FURTHER NOTES ON

TUBE WELLS

Boring, Sinking and Working for Irrigation
Purposes and Public Water Supplies

BY

T. A. MILLER BROWNLIE

C.E., M.I.W.E., M.I.M. & C.E.

Agricultural Engineer to Government, Punjab

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PREFACE TO THIRD EDITION.

SINCE 1913, when the second edition of this little book was published, considerable development in Tube Well irrigation has taken place. Over seven hundred convoluted Tube Wells of all sizes are in use in India, representing an irrigated area of over forty thousand acres. The system has also been extended to Mesopotamia and Persia.

The cultivator has realized that mechanical power is cheaper than the indigenous methods, and for areas uncommanded by flow irrigation from canals, the demand for Tube Wells and Lift irrigation is greater than the present resources for carrying out the work.

Numerous enquiries have been received regarding the diminution of supply of water from Tube Wells which have been installed by agencies apparently ignorant of the effect of pumping from the subsoil, also complaints from landowners, who have found that Tube Wells situated in neighbouring lands have ultimately detracted seriously from the available water supply in their ordinary wells; these have led me to add, in the present edition, the article on Subsoil Water in relation to Tube Wells. This, together with the several other additions that have been made to the book, will, it is hoped, be found useful.

The fact that a landowner may, without hindrance, withdraw water from under the lands of neighbours, appears to be a matter on which immediate legislation is a necessity.

January 1920. T. B.

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ORDINARY WELLS.

THE relationship between tube wells and ordinary wells is so close that a short description of the latter may be of use to those who desire to study the more modern methods of obtaining water from the subsoil.

In its ancient form the ordinary well consists of a hole dug in the ground, the depth of the hole being a short distance below subsoil water level. The well is, therefore, an artificial hole or basin with a certain depth of water in it. Obviously this type of well can only be sunk in alluvial soils where subsoil water exists, and the depth of the excavation or well is largely regulated by the depth from ground surface to subsoil water surface,—this may vary from a few feet to many hundreds of feet.

Wells which are sunk through pervious strata only to subsoil water are termed "shallow wells," irrespective of the actual measurement from ground surface to subsoil water level, and wells which are sunk through an impervious strata (generally clay), and tap subsoil water below the impervious strata, are termed "deep wells," irrespective of the depth from ground surface to subsoil water level.

It is obvious therefore that a deep well may in some cases measure actually much less from ground surface to water level than a shallow well, the terms "deep wells" and "shallow wells" having reference only to the fact whether water is withdrawn from below an impervious stratum or from above an impervious stratum.

In districts where the subsoil is fairly firm, wells may be sunk to a considerable depth without any lining or wall

to support and prevent the earth from falling into the well; such wells are generally sunk as a temporary measure or for economic reasons, as even in stiff soils rain and other climatic influences tend to erode the vertical, or nearly vertical, wall of the excavation and thus partly fill up and render useless the well. For this reason a lining, or wall of timber, or masonry is generally constructed in order to support the earth sides of the excavation.

The well lining, or "steining" as it is frequently called, may be built pervious or impervious according to the purpose for which the well is being sunk, the expenditure to be incurred and the life of the finished work.

The cross sectional shape of the well is an item which requires some consideration when the subsoil is such that a support or lining is required. This is generally either rectangular or circular, although for special purposes the section may be a polygon, hexagons and octagons being fairly common sections.

The most economical cross section for ordinary wells for water supply is the circle; the lining in this section, forming an arch, requires less material to withstand a given pressure of earth than a rectangular section, in which the lining would require to be built as a straight retaining wall and therefore more material and expense would be incurred.

The material used for forming the lining or steining of wells varies considerably in different countries and in different parts of any one country and is generally determined by the material most readily available. Iron and steel have been used in some cases but more generally when the wells are required for purposes other than water supply. Concrete and earthenware, moulded in segments, have been employed and for small diameter wells are moulded in full circular section Timber is

more frequently employed, made up from staves in the form of a large pipe to suit the size of the required well. Or bamboos are sometimes employed in this way. Masonry is much more common than any of the above, either as stone masonry, or brick masonry and considering the ease of application is a moderately inexpensive form of lining.

Sometimes the masonry is built dry, *i.e.*, without mortar, thereby reducing the cost of the work to some extent and also permitting of percolation of water through the lining, while, in solid steinings when mortar is used, pigeon-hole work is in some cases provided in the lower portion of the steining which is below subsoil water level in order to provide for percolation. Pigeon-hole work or provision of any kind for percolation through the lining or steining is not recommended; it seldom justifies the trouble and expense involved, for reasons which will be shown later. The lining used on wells is generally built on a frame, termed a "curb," which takes the place of oundations in an ordinary masonry work. This frame or curb forms a cutting edge and permits of the sinking of the lining or steining as excavation of the well proceeds. Many forms of curb have been used, one of the oldest being made from timber and is still largely used in many countries on account of its low cost. The disadvantage in a timber curb is that owing to the nature of the material a sharp cutting edge cannot be provided, the actual width of the cutting edge being several inches, and thus the resistance to sinking is considerable; while if an obstruction to sinking is met with under one portion of the curb only, its removal is extremely difficult owing to the breadth of the cutting edge. The curb with its superimposed masonry steining sinks more at the point of least resistance, thereby leaving the horizontal plane, and the well becomes crooked or out of plumb—a fault extremely difficult, if not impossible, to remedy.

Curbs made from wrought iron or steel plates are more common in recent years; these are of triangular section and thus present practically a knife edge for sinking, thereby expediting the work very considerably. One objection to this form of curb is its weight, which may add considerably to the cost of the work if the curb has to be conveyed a long distance from the place of manufacture to the site of the proposed well, and the difficulty of handling and placing in position. To obviate these defects a triangular shaped curb, made of very thin sheet iron, is frequently used; this curb serves as a mould only and after it has been placed in position it is filled with concrete. This type of curb, while preserving the correct cutting form, is strong and lasting, and possesses the advantage of being comparatively cheap.

In order to prevent the masonry steining of wells from being cracked due to irregularity or carelessness in sinking, the curb is generally tied to the steining at several points in its circumference by long iron tie rods, one end of which is secured to the curb; the rods pass up through the masonry steining and are secured by a ring washer and nuts. This form of construction secures a strong cylinder capable of withstanding the severe stresses of sinking.

In sinking these wells the common practice is to first dig a circular hole of slightly greater dimensions than the outside diameter of the steining to be built. The depth of the hole is regulated by the nature of the material in which the excavation is made, and is made to a depth that is considered safe from the possibility of material from the practically vertical walls falling into the hole and injuring the excavators.

When this limit has been reached, the curb is placed in position and filled with cement concrete, tie rods are secured to the curb and the masonry circular wall is commenced and built up to, or above, ground level. Excavation

on the floor of the masonry cylinder is continued, and as material is removed from the interior the cylinder sinks; this operation is continued until the required depth is reached. After the lower edge or curb of the cylinder reaches water level, excavation to the required depth below water is more economically carried out by a hand or power dredging machine than by hand labour of divers. Masons continue to build up the steining as the cylinder sinks, artificial weight being added to the cylinder if necessary to overcome its skin friction with the subsoil.

SUBSOIL WATER.

BEFORE considering the yield of water that may be obtained from ordinary wells a brief examination of the sources of underground water supply may be of advantage. Water is known to exist in all the alluvial deposits which cover the earth's surface. These alluvial deposits at some depth below ground surface may be considered as the lake or sea which existed in prehistoric times, but now have become filled with gravel, sands and clay according to the velocity of the water at the time the deposit of any particular stratum took place. The supply of water to this lake or sea still continues from several sources—direct rainfall over the ground surface, a certain proportion of which percolates through to the subsoil water; rainfall and melting of snow and ice on the hills and mountains; also there is percolation from surface rivers and streams.

The run-off or overflow from the subsoil water or so-called underground lake may be direct to the sea, or by drainage into rivers and streams; thus there is constant circulation or renewal of the underground supply and the rate of this circulation depends on the nature of the alluvial deposit.

If we consider an ordinary lake or pond of any size whatever, it may be only a few yards in length and

breadth or it may be hundreds of miles in length and breadth ; water flowing in at one end of the lake and escaping at the other end, we have a constant water level in that lake, and this level will only vary if we increase the rate of inflow and consequently the rate of outflow, thus raising the depth of water on the outlet cill to the sea, river, or other source of drainage. If a pipe is put into the lake and water withdrawn from it either by a pump or other lift appliance, the water level in the lake will remain constant at a slight reduction in level, so long as the quantity of water pumped from the lake per unit of time is less than the inflow or source of supply to the lake per unit of time ; there will at first be a slight decrease in the depth of water passing over the outlet cill, the difference in depth of water on this cill before and after the pump is applied representing the quantity of water withdrawn by the pump. As soon as this difference is established, then the water level of the lake remains constant at this slight reduction of level,—this level is continuous over the lake surface at every point and does not vary even at the pump. (*Note.*—On large lakes where tidal effect is noted and where the water surface is curved in accordance with the earth's surface, these facts make no difference to the general principles noted above, the water surface being considered a level plane as in a small lake or pond.)

Now consider the same lake filled with large stones or boulders and these stones packed up to a more or less level plane some considerable distance above the water level of the lake, what now would be the effect of pumping water from this lake ? The filling of the lake with stones would, of course, cause displacement of water equivalent to the volume of stone *less* absorption ; after that displacement had taken place the water level would remain constant as before and the effect of pumping would be exactly the same as in the previous case. This, of course

assumes that the interstices between the boulders are so large that the flow of water through the lake and to the pump is not measurably interrupted.

If, however, instead of large stones we fill the lake as before with fine gravel, then the conditions are somewhat altered. The interstices between the small stones are now much smaller and water does not pass through the gravel so easily:—the result is that at the inlet end of the lake there is a slight increase in the water level and from this point to the outlet end there is a slight slope on the water surface—a hydraulic gradient; this slope provides the necessary head required for the flow to overcome the friction against the gravel filling. Similarly in pumping water from this gravel filling, as soon as the pump is started there is a slight decrease in the water level immediately surrounding the pump suction pipe; this decrease is the head required by the water to overcome the friction in flowing through the small interstices of the gravel to meet the requirements of the pump.

Instead of gravel the lake may be filled with fine sand, then the hydraulic conditions are similar to, but much more marked than in, the case of gravel. The hydraulic gradient of the lake or subsoil water is very clearly defined and can be readily measured, a much greater head being required to maintain water motion through the small interstices of the sand particles. In this case the interstices are so fine that they act as capillary tubes, both horizontally and vertically. When pumping water from this sand-filled lake, the depression in the water level around the suction pipe of the pump necessary to overcome the friction of the fine interstices of sand to the passage of water is very marked, the depression starting some considerable distance from the suction pipe, increasing gradually until fairly close to the pipe when the descent is rapid. This depression is frequently spoken of as the "cone of depression," but the

shape may be more correctly likened to a flaring trumpet mouth than to a cone.

So far we have considered a lake which is supplied with water at one end, the drainage taking place from the other end; in the case of the stone-filled lake, a road or pathway over the rough irregular surface is quite possible, but a river or stream would not flow over the surface, the interstices between the stones being so large all water would flow through the stones immediately on coming in contact with them at the edge of the lake. In the case of the sand-filled lake however, the matter is somewhat different; a river or stream might flow for some considerable distance over such a surface, the interstices of the sand being small, absorption would be somewhat slow and the river might pass right across the surface of the sand-filled lake, losing a portion of its volume in its passage. The effect of this percolation or seepage from the river is, of course, in the first instance, a further source of supply to the subsoil water, the more important aspect is that owing to the capillary nature of the interstices of the fine sand the seepage causes a "humping up" of the subsoil water level along the line of the river.

If the surface river runs transversely to the inlet and outlet line across the lake, or in other words at more or less right angles to the hydraulic gradient, then the effect of the humping up or wave of subsoil water is very considerable as it affects the hydraulic gradient, flattening it somewhat on the upstream side and increasing it on the downstream side of the interruption. A humping up of the subsoil water level is also caused by the application of water to the surface of a portion only of the area under investigation, heavy rainfall or irrigation will cause this, and in suitable soils the recession of the humped portion to its original level often takes many months.

So far we have considered at one time subsoils of one material only; in nature these subsoils varying from the coarsest of gravel or boulders to the finest clay are frequently met with in one vertical section of alluvial deposit, the strata also generally varies from one part of the area to another, the heavier material such as boulders, etc., being deposited where the water velocity is highest, gravel, etc., in the region of next higher velocity, and in the regions of lowest velocity we find that the finest clay forming silts are deposited. It is for this reason that the water yield of ordinary wells when situated close to one another may vary very considerably. In two wells of equal depth the curb of one may be in moderately coarse sand through which water passes somewhat freely, while the curb of the second well may be in fine sand mixed with clay through which there is considerably more resistance to the passage of water and consequently the yield of the second well is much less than in the former case.

CRITICAL VELOCITIES FOR ORDINARY WELLS.

MOST people are aware that only a limited quantity of water can be taken from any well ; this limited quantity, which is the safe yield of the well, represents a maximum velocity of water passing through the subsoil (sand, gravel, etc.) which forms the well floor, without disturbing the arrangement of the finest particles forming the flooring.

The velocity at which this disturbance commences is known as the "critical velocity," and this varies with different qualities of subsoil. For instance, in a well sunk in gravel the water passes through this material at a comparatively high velocity before the smallest pebbles are displaced, whereas in a well sunk in sand the critical velocity is much lower, the finest particles

of that material being more readily displaced than small pebbles.

Water may be withdrawn from any well for an indefinite period without damage to the well, provided the critical velocity is not exceeded, but, if the rate of withdrawal of the water exceeds the critical velocity the effect is as follows :—The finest particles of sand at and near the surface of the floor of the well are the first to be displaced, these will be in partial or full

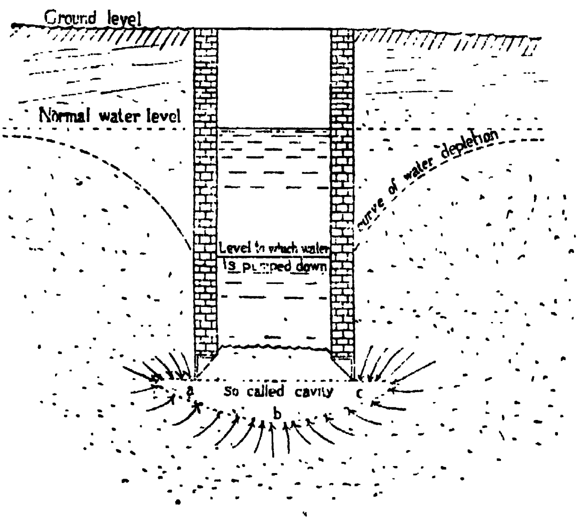


Fig. 1.—Illustrating disturbances and cavity formed under well when critical velocity is exceeded.

suspension, according to the velocity of the water; fine particles from the layer below the surface will travel upwards to replace the voids left by the particles from the surface layer, and these in turn will be carried to the well. This action extends below the level of the bottom of the walls or curb of the well and also extends laterally; the fine particles flow in from under the walls,

the density of the subsoil is being altered, the spaces between the particles of sand increased.

The disturbance of the subsoil is within a roughly shaped plano-convex figure, on the plane surface of which the well rests, and the superficial area of the whole figure (excluding the well area) is such that the water passes through this surface at the critical velocity for the subsoil. (See Fig. 1.)

What then is the result of exceeding the critical velocity of a well? (*a*) The finest material is washed into the well and forms a new floor in the well above the level of the old floor, *i.e.*, silting occurs, and part of this material remaining in suspension is removed with the water. (*b*) The subsoil under the well is loosened and the well tends to sink and is liable to collapse.

Various expedients have been tried in order to increase the yield of wells beyond their critical velocities; one of these is to fill in the floor of the well to a certain depth with gravel of various sizes, arranged somewhat in the manner of a percolation filter, but in reverse order; this has not proved satisfactory, as after a short time the well again becomes silted by sand, etc., being carried up through the interstices of the stones. Exactly the same feature is observed in ordinary water filters when worked too rapidly; when sand of varying grades of coarseness forms the floor surface of wells, it has been found that the fine particles are disturbed at velocities of 2½ feet to 3 feet per hour, *i.e.*, the critical velocity.

Another method is to cover the floor of the well with a fine straining material, and this also has proved unsatisfactory on account of the finest particles of the subsoil being washed through the strainer and silting on its upper surface, while at the same time the coarser particles pack on the underside of the strainer, thereby

reducing the flow until the yield ultimately falls again to the critical velocity.

Many engineers have endeavoured to increase the yield of wells by sinking the wells deeper than is actually required to provide a suitable depth of water over the mouth of the suction pipe and from the mouth of the suction pipe to the floor of the well. For example, assume that a certain well of 12 feet diameter is sunk to a depth of twenty feet below normal water level and the subsoil at the floor of this well is fine sand having a critical velocity of 3 feet per hour; then the safe maximum yield of the well is A′ = area of well = 113 sq. feet × 3 feet per hour = 2,119 gallons per hour. Now by sinking this well so as to have a depth of, say, 40 feet of water in the well, no increase of yield can be expected because the sand at the bottom of the well will still be disturbed if the velocity is increased above 3 feet per hour in spite of the extra depth of water, or, as it is sometimes called, the water cushion. Where an increased yield has been obtained after deepening a well, it has been proved that the well is actually gradually silting up, or else by deepening, a coarser and therefore more porous subsoil has been entered, such a subsoil having a higher critical velocity.*

Experiments on the yield of ordinary wells have been carried out for over 30 years by various engineers in various parts of the world, and the conclusions drawn from these are that it is unsafe to withdraw water for any length of time at a rate exceeding the critical velocity of the subsoil of the well. The critical velocity in sand of varying degrees of fineness has been found to be between 2½ and 3 feet per hour, but in coarse sand

* See Public Works Department paper No. 178, by Mr. Dawson, Manual of irrigation wells, by Mr. Maloney.

Punjab Public Works Department paper No. 63, Notes on the yield of wells, by the Hon'ble Mr. J. T. Farrant.

of *uniform* grain a slight increase in this critical velocity has been observed.

CRITICAL VELOCITIES FOR TUBE WELLS.

IN order to find the critical velocities in sand when tube wells are employed, the writer fitted a short length of straining tube horizontally in a tank, one end of the tube discharging through the side wall of the tank.

The tank was then filled with a mixture of fifty per cent. fine sand and fifty per cent. coarse sand, the fine sand being that which would pass through a sieve of 1,600 meshes per square inch, and the coarse sand that which was retained on the same sieve.

The tank was then gently filled with water, spreading plates being used to prevent disturbance of the sand, observations were made of the effect on the sand of various straining velocities; the water level being kept constant at the head under observation. These experiments show that with a velocity of six inches per second through the strainer, the finest sand passes through the strainer and is discharged at the pipe mouth in considerable quantities, the coarser sand packing up on the outside of the strainer, and after a short time blocking up to such an extent that the flow is considerably reduced, and the velocity from the tube is insufficient to carry off all the fine sand which has passed into it. Similar results, but less marked, were observed on all heads creating velocities down to two and a half inches per second, and on velocities of less than two and a half inches per second, the fine particles of sand close to the strainer were carried through the strainer, and discharged from the tube during the first few minutes of flow, and packing on the outside of the strainer was observed to a slight extent. At velocities of three quarters and half inch per second there was no apparent

change in the sand structure surrounding the tube and only a slight trace of sand was discharged for a few minutes on starting the experiment, after which the water was free from sand.

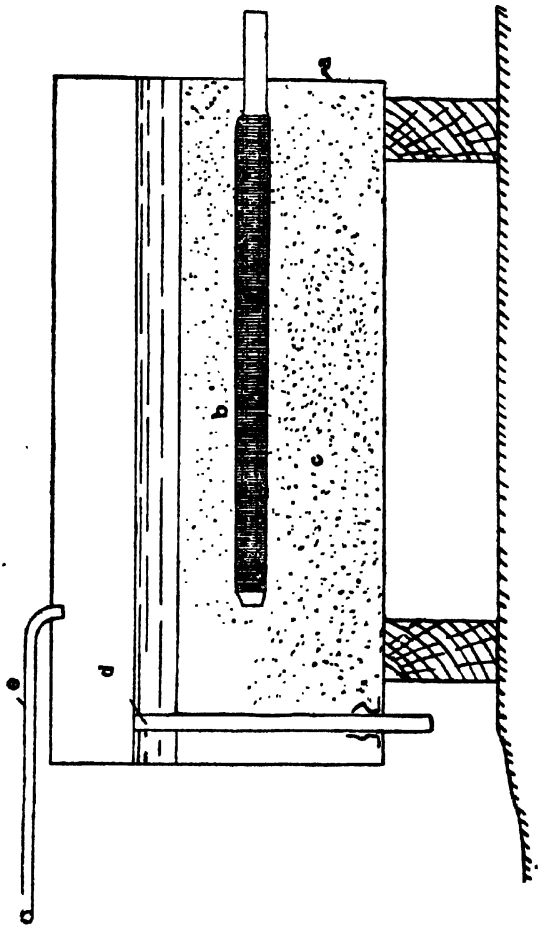


Fig. 2.—(a), Tank; (b), straining tube; (c), mixture of coarse and fine sand, fine sand being dyed red; (d), over-flow pipe which can be raised or lowered; (e), inlet pipe.

The conclusions to be drawn from these experiments appear to be that a safe mean velocity for tube wells is half an inch per second, and also that a very fine

straining material is unnecessary, provided this velocity is not exceeded, and the diameter of the tube is such that the delivering velocity will be at least three and a half feet per second: this velocity is necessary if the water is to keep in suspension the fine sand passed by the strainer. At first sight there appears to be an inconsistency in so far that in average sand examined in the floor of an ordinary well the critical velocity is approximately half an inch per minute, while with a tube well sunk in the same sand the critical velocity appears to be half an inch per second or sixty times greater. This difference is however only apparent and examination shows that the critical velocity of the sand is in no way changed. Consider a tube well composed of a fine screen, one foot in diameter and of unit length, sunk in average sand, we find that water can be withdrawn from this tube at a velocity through the screen of half an inch per second and a small quantity of the finest sand may be washed into the tube during the first few hours of flow; the particles of sand appear to bridge over the interstices of the screen and themselves form a screen preventing the passage of more sand into the tube, the actual critical velocity line being thirty feet distant from and concentric with the tube, and at that point the velocity through that imaginary line is half an inch per minute, or the true critical velocity for the type of sand under observation.

If there is a little clay mixed with the sand then the critical velocity of the tube may drop very considerably as some varieties of clay do not easily wash free from the sand and in the high velocities close to the tube the clay packs with the sand and helps to reduce the apparent critical velocity, although water may be withdrawn at a considerably higher rate than would be the case in an ordinary well sunk in the same material.

THE GENESIS OF TUBE WELLS

THE tube well, as we know it to-day, has been produced by a comparatively slow process of evolution from the ordinary ancient well, and the almost imperceptible change, from the drawing of water vertically from a horizontal surface of water bearing stratum, to the drawing of water horizontally from between the layers of numerous strata, appears to have been made first some fifty years ago in California. In its earliest form it consisted of a circular hole cut in the ground, and carried to some considerable depth into the water-bearing stratum ; into this hole the pipe through which the water was to be withdrawn was inserted, the mouth, or lower end of the pipe, being kept rather more than midway between the subsoil water surface and the bottom of the hole or well. The space below and surrounding the pipe was filled in with broken stone, generally of a coarse grade, resembling road metal. Wells of this form yielded a higher discharge than the ordinary well, and were considerably cheaper to construct, but, as is obvious, they could only be successful in a porous subsoil, such as various grades of gravel. In districts where this type of tube well was found to diminish in discharge after a short period of working, it was discovered that such diminution was due to sand and fine particles of subsoil having been washed into the interstices of the stone shrouding, and gradually choking the draw-off or suction pipe.

To correct this failing, it was necessary that the velocity of the water passing through the subsoil should be reduced to such an extent that the finer particles of subsoil would not be held in suspension, and in order to achieve this a longer pipe was used and was perforated with a large number of holes of various diameters along its walls; thus, the stream of water to the tube

was distributed over a greater area, and hence the velocity was reduced. Owing to the length of the tube employed, however, it could no longer be inserted in a well-like hole, as in the earlier forms, and therefore sheet iron casing pipes were employed, and the material dredged out from the interior. The perforated tube was lowered and shrouded with broken stone, and then the casing pipe was withdrawn.

Tube wells constructed according to this method proved highly satisfactory in coarse subsoils, but in districts where the subsoil contained much sand the tubes choked sooner or later; consequently, methods had to be found for excluding sand from the tubes in a more satisfactory manner than had been attained by using broken stone as a screen.

USE OF WIRE GAUZE.

In the early seventies, development was so rapid that it is difficult to follow the various stages, but the introduction of a fine woven wire screen wrapped round the perforated tube constitutes the main feature. The larger sizes of tubes, when made in this form, were sunk in the old way by first sinking a casing tube, but smaller sizes were provided with a driving point and driven direct into the earth, a protective covering of perforated metal being wrapped over the wire gauze in order to protect the fine screen from damage due to friction with the soil. The objection to the use of a wire screen in contact with a perforated tube is the enormous loss in the waterway area of the tube, which is accounted for as follows: Assume the wire screen to be of the ordinary square mesh pattern, having, say, 2,500 meshes to a square inch, or fifty spaces to a lineal inch. In a gauze of this description, the thickness of the wire is practically equal to the space between the wires, so that, considering the wires lying in one direction only, the original area of the

hole is reduced by one-half by these wires alone, and the effect of the wires lying at right angles to the first lot further reduces the remaining area by one-half, leaving only one-fourth of the original area as an available waterway, the loss being seventy-five per cent. When the tube body has been perforated with the maximum number of holes consistent with the strength necessary to resist the pressure and other stresses to which it will be subjected, then the length required for a given discharge has to be increased *four fold* when the tube is to be close wrapped with a wire screen ; thus increasing the cost very considerably both of the tube and of the boring necessary for its installation.

ABYSSINIAN TUBE WELLS.

FOR small quantities of water the type of tube well, familiar to most people, is the Abyssinian pattern. This consists of a short length of four or five feet of one and a quarter or one and a half inches diameter wrought iron tube, perforated with small holes and having wrapped round it a layer of fine copper or brass gauze to act as a straining material ; over this, as a protection to the gauze, a layer of perforated thin sheet metal is secured. One end of this straining tube is provided with a steel driving point and the other end is connected to a length of plain wrought iron tube. The tube well thus formed is driven vertically into the ground and a hand pump is attached to the upper end of the plain tube.

When water is pumped from the Abyssinian tube well there is at first a considerable quantity of fine sand delivered with the water and if pumping is continued the flow of water will gradually diminish and probably cease altogether. This stoppage of flow is caused by the comparatively high velocity of water through the straining material, bringing with it the finer particles of sand, some of which pack up on the outside of the

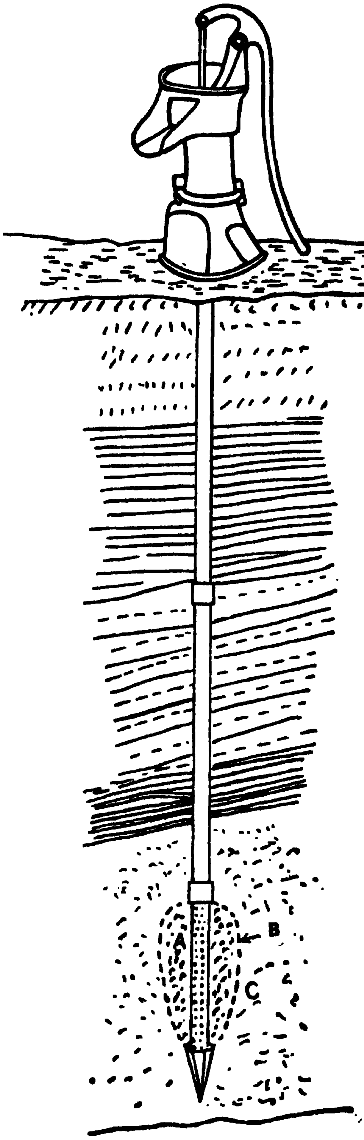


Fig. 3.—Abyssinian Tube Well. A.—The so-called cavity.
C.—Undisturbed subsoil.

straining material forming an almost impermeable "conglomerate," the remainder pass through the straining material and are carried up to the pump, but, as packing round the straining material increases, the velocity is insufficient to carry the particles to the pump and they settle at the bottom of the tube well, gradually closing up the inside of the strainer.

In order to obtain a constant supply of water from these tube wells they require to be "educated up" to the demand to be made on them. On the first sign of diminution of supply, the pump plunger should be operated to allow air to pass below it and suddenly release the head caused by the vacuum due to pumping, thus a reverse flow through the strainer is caused which displaces the finer particles of sand and, on again pumping, these are carried through the strainer up to the pump. By repeating this operation several times the sand surrounding the strainer is washed of its finer particles, and a pear-shaped cavity of coarse sand is formed round the strainer. When this stage is reached the tube well is giving its best results and any more convenient form of pump may be substituted for the "sinking" pump; it must, however, be noted that the power of the pump should remain the same as that used for sinking. If a more powerful pump is employed, then the coarse sand cavity is enlarged owing to the increased velocity through the strainer carrying more of the fine sand into the tube, and the clearing operations have to be again performed until the subsoil surrounding the strainer adapts itself to the new conditions imposed by the higher power of pump.

Fig. 3 shows the Abyssinian tube well and the approximate shape of cavity formed round the short strainer, this so-called cavity is only a cavity in the sense that it does not contain the finer grains of sand.

The dotted line B, Fig. 3, represents the point of change from the ordinary stratum to the washed sand free from fine grains surrounding the strainer. The cubic capacity of this cavity can be calculated as its superficial area is such that the water pumped passes through this surface at a velocity of from half an inch per minute to three quarters of an inch per minute; these velocities being the critical velocities for sandy and clayey soils, therefore, if the stratum is known, the size of cavity can be fairly accurately computed.

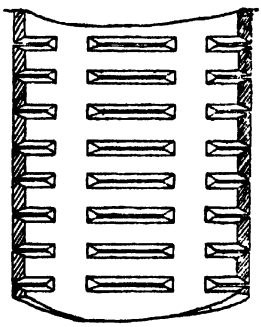
Experiments with Abyssinian tube wells show that when pumping is carried on at a rate which represents a velocity through the strainer of half an inch to one inch per second, the well will yield a constant supply of water free from sand; with velocities above one inch per second, traces of sand are frequently found in the water, and in strata where sand is fine, velocities of two and three inches per second will absolutely choke up the tube well.

This type of tube well is, of course, limited to comparatively small supplies, five gallons to fourteen gallons per minute, or say up to 800 gallons per hour, large tubes cannot be driven into the ground as they are liable to split, and the fact that the gauze straining material is placed in contact with the perforated tube reduces the waterway area by seventy-five per cent., that proportion being taken up by the wires forming the gauze. Owing to the fineness of the wires necessary in a small mesh gauze, the straining material is extremely perishable and requires renewal, on an average, every two years.

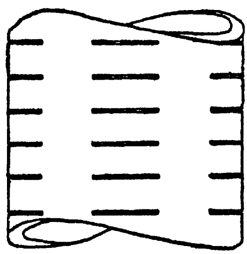
COOK'S TUBE WELL.

The American patent tube well, known as "Cook's Tube," has been in use for a number of years, and the sizes commonly in use are for discharges of seven to eight thousand gallons per hour.

This tube well consists of a plain brass tube having throughout its entire length, and at intervals of approximately one-fifth inch, circumferential slots about one inch in length, for general purposes a width of slot of one hundredth part of an inch is suitable ; the metal at the edges of the slots is bevelled off on the inside of the tube, in order to allow grains of sand which are carried up to the slot during the clearing operations, passing easily through into the tube, instead of packing against the outside and partially closing the slot. Fig 4 shows the arrangement and shape of slots employed. Supposing a tube well is required for a supply of 5,000 gallons per hour and the subsoil water level is not to be reduced at the tube more than five feet, then by Weisbach's formula a three-inch pipe, delivering 5,000 gallons per hour, will absorb 2·9 feet in friction in a length of 100 feet, the velocity in the tube being 4·5 feet per second. In a three-inch pipe one inch long there will be 45 slots, each $\frac{3}{4}$ inch long, and say one hundredth of an inch wide ; then for a velocity of one inch per second through the slots, the total area of slots would require to be ; area in square feet $= \dfrac{\text{discharge in cubic feet per second } 0{\cdot}22}{\text{mean velocity in feet per second } 0{\cdot}08} = 2{\cdot}75$, and 2·75 square feet represents a tube length of 98 feet.



SECTION.



ELEVATION

Fig. 4.—Cook's Tube Well.

A greater velocity than one inch per second would result in packing of the sand particles against the slots at the upper end of the tube where the suction effect is greatest and the slots would be gradually closed up, resulting in a higher velocity through the remaining slots and consequently hastening the closing of these also; as the closing of the slots is in progress the finer particles are passing more rapidly through the slots, and the proportion of fine sand to water becomes such that the interior of the tube also is closed, and requires to be washed out before pumping can be continued. The experiments made with this type confirm the assumption that with tube wells the critical velocity is between half an inch and one inch per second, or say sixty times the critical velocity in open wells. The Cook's tube is perfectly suited for moderate supplies but, being somewhat difficult to slot, is expensive. On the other hand, it is capable of being sunk without a casing pipe.

TUBE WELL AT LAHORE.*

In 1909 a tube well was sunk at Lahore; this consisted of 40 feet of $4\frac{1}{2}$ inches diameter wrought iron pipe perforated with holes, the total area of the holes amounted to 14·1 square feet in the 40 feet length of tube. This tube, the metal of which was $\frac{3}{16}$ ths inch thick, was wound with a spiral of brass wire, $\frac{1}{8}$ inch diameter, and over this wire fine brass gauze 40 meshes per lineal inch was wrapped. In gauze of this mesh the waterway area is 55 square inches per square foot, and as the diameter covered by gauze was $5\frac{1}{8}$ inches, therefore, in the length of 40 feet there were 68·76 square feet of gauze having 26·26 square feet of waterway area, or almost twice the area of holes in the tube.

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* *Vide* Punjab Public Works Department paper No. 62, Tube Well Experiments, also paper No. 63, Notes on the Yield of Wells, by the Hon'ble Mr. J. T. Farrant, Chief Engineer.

The change in velocity of water passing through the gauze, and thence through the holes, caused by this great difference in waterway area, produces eddies in the tube, and diminishes to a very large extent the discharge. This tube well under a head of 7 feet discharged 3,000 gallons per hour or 8 cubic feet per minute, the actual head absorbed in pipe friction being 0·3 foot and the approximate head absorbed between strainer and perforations being 4 feet.

The velocity through the strainer being greater than the critical velocity in unprotected sand, resulted in a certain amount of sand being brought into the tube which accumulated under the low heads and was disturbed, and carried out of the tube under heads from 10 to 14 feet, when the discharging velocity rose to 2·6 feet per second, that velocity being sufficient to hold most qualities of sand in suspension.

The experiments were of short duration and none appear to have been carried out for more than twenty to thirty minutes at one time, and the constant starting and stopping of the pump at such short intervals is bound to have produced an oscillation in the water column in the tube, the effect of which is exactly similar to that created in the Abyssinian tube well in order to clear the fine sand from the strainer.

With a gauze of 40 spaces to the lineal inch, the safe head would be approximately 7 feet, and if a pump with capacity of 3,000 to 3,500 gallons per hour had been employed constantly for eight or ten hours per day, there is no doubt that all sand would have been removed from the tube in a day or two, and the after discharge would have been steady and free from sand.

The experiments are of interest in so far that they show the loss in discharge caused by the large difference in waterway area of the straining material and

perforations and they mark the commencement of a system of water supply in India which has borne considerable fruit. This type of tube has been in use in America for very many years and is known as the Thompson tube (Fig. 5). Owing to the fragile nature of the wire screen employed it is liable to be pressed against the perforated tube between the coils of the wire sustaining spiral, and thus defeat the object of its construction.

OTHER FORMS OF TUBES.

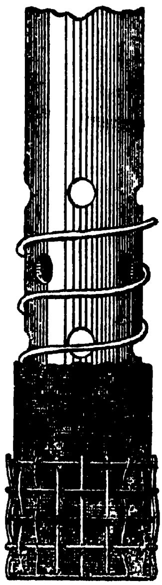


Fig. 5.

In order to strengthen the fragile gauze used in this type of tube well or strainer, the tube is further protected either by an outer covering of heavy wire netting, or by an outer and reversed spiral wire as in the Moresi tube. In order to reduce the cost, the distance and outer nettings or wires are usually made from a metal inferior to that of the fine gauze or actual screen, so that the combination is only suitable in districts where the subsoil water is free from acid, or unfitted for setting up galvanic action. The writer used this combination screen as a temporary measure, in 1912, on a convoluted tube well at Dera Ghazi Khan, where the water is somewhat saline, the result being that within six months the outer screens were completely corroded, the iron oxide in combination with the silica forming practically an impervious matrix on the surface of the screen proper, and thereby defeating the object of the tube.

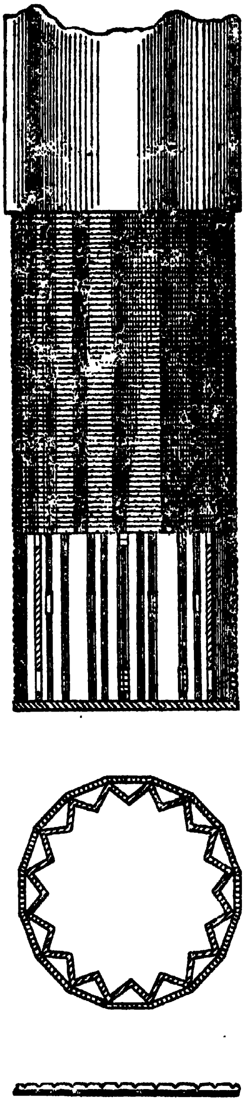


Fig. 6.

'There are two main objections to the use of square meshed gauze as a screen, the chief being that owing to the fineness of the wire required to obtain a correspondingly fine mesh, the material is fragile and easily damaged and has practically no margin to allow for the corrosion which may take place in certain soils, and although tube wells with these fine gauze screens have worked successfully for periods of twenty years in several districts, yet these cases may be taken as the exception rather than the rule. The other objection is that this form of tube requires to be sunk inside a casing tube, which is withdrawn after the tube proper has been placed in position, and this necessitates the installation of a tube of considerably less diameter than the casing tube employed so that for the boring done the discharge is less than would have been the case if the tube well had been sunk without a casing.

These early designs for tube wells, having a heavy and substantial screen of fine aperture, include the Smith tube, where the screen is a metal plate, with

apertures formed by a cut on three sides of a rectangle, which is then upset so as to leave in the plate a fine slot of the required opening.

One form of heavy pattern tube is Stuke's design (Fig. 6), consisting of a star-shaped body, round which is wound a wire of ordinary circular section, which acts as the strainer, the water passing between each turn of the wire which is serrated at regular intervals. A modification of this are two forms of oil well tube, in which the circular wire is not serrated, but is wound with a

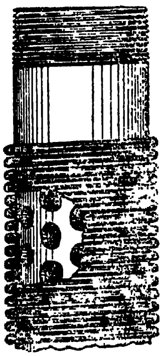


Fig. 7.

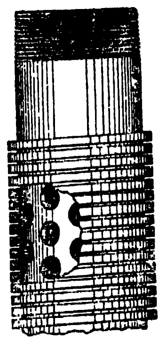


Fig. 8.

OIL WELL TUBES.

waterway space between each turn of the wire, while in order to obtain the advantage of the V-shaped opening, described in Cook's tube, the wire is drawn to a more or less triangular section. This strainer is applied to a plain perforated pipe, and is made with either galvanized iron or brass wire so that a heavy make of tube can be obtained at a very reasonable cost.

Tube wells built up of a skeleton framework, covered with wire winding similar to that on the oil well tubes have been used to some extent in India, and from those which have come under my notice it would appear that

there is considerable difficulty in manufacture. In some cases the wire winding has been so close that the tubes were practically watertight and apparently this defect had not been observed before the tubes were despatched to the purchasers. In one case six tubes of this type were issued to a purchaser who, after one had been sunk and no water obtained, asked me to investigate the matter. I found that the five tubes not already sunk were overwound and could not possibly pass water, the conculsion being that the tube already sunk contained the same fault.

In some cases the wire is wound with correct spacing between each turn, but is so loose that it slips on the framework when the tube is handled and thus large openings are formed which permit the passage of sand. A feature of the Oil Well Tube is the rigidity with which the wire winding is secured to the tube body.

RECENT TYPES.

A TUBE WELL of more recent origin than the foregoing is the "Treble Shell Screen," suitable for insertion in certain soils without a casing tube. It consists of a wrought iron pipe the perforations of which are countersunk to an area of four times the area of the perforation ; the tube is then covered with a galvanized spacing net, over which is secured slotted, quicksand, copper wire covering, protected from damage in sinking by galvanized steel straps ; this tube is claimed to be indestructable, but it requires a length of six diameters to secure a waterway area equal to the tube diameter. Other recent forms include the "Johnston" all brass screen, the ribbon tube well, and the convoluted tube well.

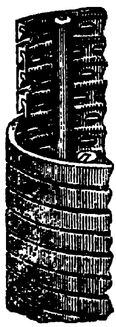


Fig. 9.

The "Johnston" all-brass screen (Fig. 9) consists of a cage shaped frame, formed by vertical rods held in position by annular rings; the screen proper being formed from brass rings of an approximately Z-shaped cross section, where one portion of the Z forms the outer surface of the screen, presenting a V-shaped annular slot for the passage of the water, while the other portion of the Z, forming the inner surface, is perforated. This form possesses the advantages of Cook's tube, without the blinding action noticeable on single body tubes, and, therefore, a shorter length of tube is required for a given discharge. This tube can be sunk without a casing tube, but engineers in the United States generally prefer to sink the casing tube to the full depth, and thus avoid any risk of damage to a tube of which the initial cost is high.

The ribbon tube well, as its name implies, consists of a specially shaped ribbon, wound upon itself somewhat as a pipe lighting spill is made from paper; the ribbon is so shaped that a waterway passage, varying in width from ·004 to ·03 of an inch, is obtainable, the cross section of the inlet being V-shaped as in Cook's tube. When heavy ribbon is employed, tension straps are attached to the outside, and this forms the complete tube well. Tubes made in this manner have been in use for several years in Southern India, but in the United States a light section of ribbon is employed as a screen only, and this is applied to a standard form of tube body.

Tube wells made in such a way that the discharging current is in direct contact with the straining material, then the discharging current acts as a blind on the surface of the strainer, and prevents the free passage of water through the strainer. This blinding action takes place whether pumping is done from the top of the strainer or the bottom; in the latter case, friction is at least doubled, and the blinding action correspondingly intensified.

Investigations made with a small tube, composed of straining material only, show that with an inlet velocity through the straining material of half an inch per second, and a delivering velocity from the tûbe of approximately three feet per second, the particles of water pass through the strainer, and creep along its inside for a distance which may be as much as quarter of an inch, before they are caught up in the current created by the suction tension. This feature is well known, and the Cook's tube and Smith's well casing are designed with their slots at such a distance apart that the particles of water passing through one slot have freed themselves from the tube surface, before reaching the next slot. The remedy would appear to be the introduction of an inner perforated tube, having the perforations large enough to prevent blinding and the area of metal sufficient to retain the high velocity current in the inner tube; the water passing through the straining material would then follow the line of least resistance and stream direct to the inner tube, there being caught up in the high velocity current.

A tube well of this form would be considerably shorter for a fixed percolation velocity than a tube well composed of straining material only.

THE THEORETICAL TUBE WELL.

THE observations on the foregoing types of tube wells, and from the experiments on straining tubes and screens result in the following conclusions.

That the straining material should not be in direct contact with the perforated tube as the area of perforations is thereby reduced by the amount of wire or other material composing the portions of straining material which are in contact with the perforations.

The straining material should be a certain distance away from the perforated tube, and this distance should be such that the waterway area, in the straining material, is equal to the waterway area in the perforated tube, thus causing no change in velocity between the straining material and the tube.

The critical velocity for tube wells in very fine sand may be taken at half an inch per second, or sixty times greater than for ordinary wells.

The discharging velocity should be not less than three feet per second nor more than five feet per second.*

The superficial area of metal in the perforated tube should be more than twice the area of perforations, in order to prevent eddies or back flow at the perforations.

The straining material should present a maximum amount of waterway area per foot length of tube, consistent with fine openings and heavy wire or other material which will withstand moderately rough handling in transport, and lowering, and will be lasting.

CONVOLUTED TUBE WELL. (*PATENTED.*)

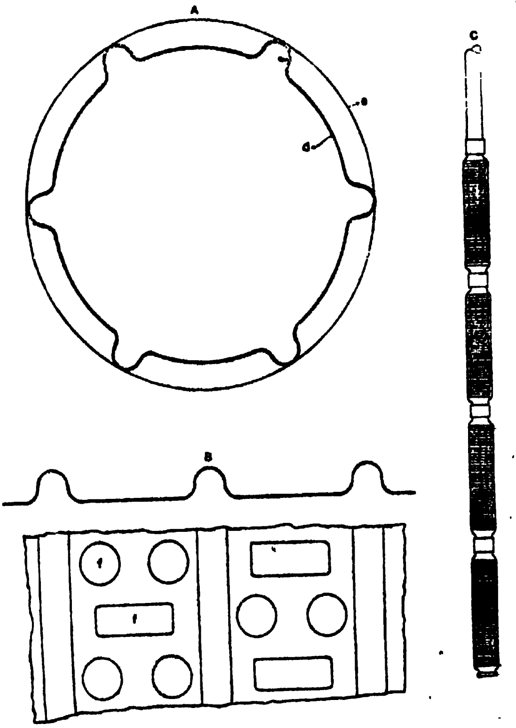
THE writer in designing this form of tube well has endeavoured to meet the above requirements. Fig. 10 shows the general design of this tube which is made of thick sheet steel, is light for transport and easily handled when sinking. The longitudinal convolutions render the tube exceedingly strong and rigid and are made of such a depth that there is no increase in velocity between the straining material and the perforations in the tube.

The proportion between the area of perforations and the area of metal is such that eddies are reduced to a minimum, and "creeping" along the inside of the

* This corresponds with the practice of pump manufacturers.

straining material is also prevented, the discharging current being concentrated, the fine streams of water percolating through the strainer pass straight through the short intervening space into the main perforated tube.

The straining material consists of heavy copper wires lying parallel, the necessary fine space being maintained by the wires being woven at short intervals,



A.—Cross section of convoluted tube well; (d). body of tube; (e). straining material.

B.—Piece of convoluted sheet before forming into tube. (f), perforations in sheet.

C —Elevation of convoluted tube well.

Fig. 10.

with pairs of fine copper ribbons which prevent slipping, or other alteration of the position of the wires when the tube is handled or in sinking. This form of straining material has about ten times the life of copper gauze, and is very considerably stronger.

Before the copper straining material is fixed, the tubes are treated to two coats of Callendar's "Kalbitum" as a rust preventative.

Convoluted Tube Wells are made in several sizes for discharges, varying from one quarter to two cusecs; or in other words, from 5,625 to 45,000 gallons per hour, these sizes have been standardized and are all made from the plain sheet on one machine, this resulting in remarkably cheap tube wells.

When used for increasing the supply of water to an ordinary well, the upper end of the "convoluted" tube should have a length of plain tube attached to it; this plain tube should be sufficiently long to project at least two feet above the floor of the well, and the top of the convoluted tube should be not less than ten feet below the floor of the well. In deep wells the plain pipe should project inside the well to not less than seven feet below the normal water-level. There are certain conditions of subsoil when this position of tube well has to be considerably altered, but generally, the above arrangement is satisfactory.

Convoluted Tube Wells are particularly adapted for direct pumping from the tube, and in cases where spring level is near the ground surface, the plain pipe may be used as the suction pipe of the pump. When spring level is at a considerable depth below ground surface, then an alteration has to be made in the plain tube to take a suitable deep well pump.

A recuperation curve is shown for a "Convoluted" tube well designed to discharge one half cusec or 11,250

gallons per hour, when working under a head of seven feet. The actual discharge is approximately twenty per cent. greater than the tube was designed for, and

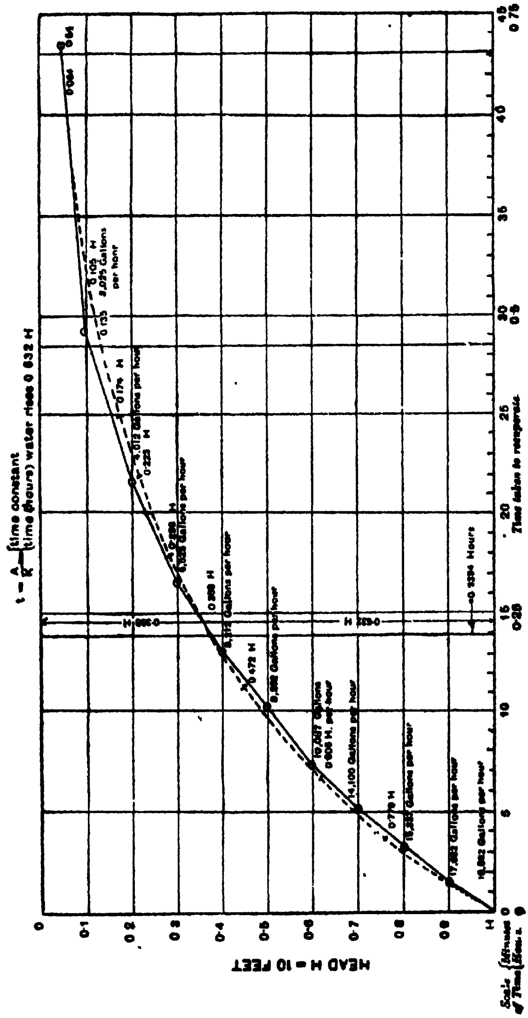


FIG. 11.

RECUPERATION CURVE FOR 5-INCH CONVOLUTED TUBE WELL.

Note.—The full line shows the recuperation curve plotted from each foot recuperated. The dotted line shows line of theoretical curve calculated from the time constant of the tube.

the recuperation curve plotted from the actual discharges under each foot of head practically coincides with the theoretical recuperation curve, plotted from the "time constant."*

The recuperation curve clearly shows that the discharge varies directly as the head, and this well known feature tempts some users of tube wells to increase the head and obtain a larger supply of water. The result of such increase of head is that the critical velocity is exceeded, and the tube well is sooner or later silted up and rendered useless.

Why should a Convoluted Tube Well yield more water than an ordinary well is a question frequently asked, and the reason is that when the tube well is first sunk, and water withdrawn from it, a certain amount of sand comes away with the water; if pumping is continued at the same rate the proportion of sand gradually diminishes until it ceases altogether and a supply of clear water is obtained. What has happened round the strainer of the tube well is that the fine particles of sand have been washed through the straining material into the tube, and the tube being of small bore in comparison to the quantity of water passing through it, the velocity of water up the tube is sufficient to carry the sand with it, keeping the inside of the tube and strainer free from silting. The subsoil surrounding the strainer has become freed of its finer particles, and therefore has a higher porosity than the undisturbed subsoil; this freeing of the subsoil surrounding the strainer takes place within a roughly pear-shaped or conical figure, of which the tube well is the axis; the

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* I am indebted to the Hon'ble Mr. J. T. Farrant, late Chief Engineer, Punjab, Public Works Department, for his original formula for the "Time Constant" for recuperation tests.

surface area of the figure is such that the water passing through this surface has a velocity not exceeding the critical velocity for the subsoil, therefore surrounding the strainer we have what is usually called the "cavity" and which is only a cavity in the sense that it is freed from the smaller particles of sand and contains the coarser material loosely packed. The writers' experiments have shown that this coarse material arranges itself around the strainer according to size of grain, the largest being next to the strainer, then the second largest and so on, to what might be termed the "critical velocity limit," that is, where the disturbed merges into the undisturbed subsoil.

It is this "critical velocity limit" or surface area of the so-called cavity which must be compared with the ordinary well as the water is passing through it at exactly the same velocity as it would pass through the floor of an ordinary well.

In a tube well designed to discharge 45,000 gallons per hour in moderately fine sand the approximate superficial area of the "critical velocity limit" would be 2,880 square feet, because 45,000 gallons per hour is equal to 2 cubic feet per second, equal to 120 cubic feet per minute; and 120 cubic feet passing through a surface at a rate of half an inch or one-twenty-fourth of a foot per hour = 120 × 24 = 2,880. An ordinary well in the same subsoil if worked not to exceed the critical velocity of the subsoil would theoretically require to have a floor area of 2,880 feet, that is to say, it would require to be 60½ feet in diameter.

In making the above calculations friction of water passing between the grains of sand situated between the "critical velocity limit" and the tube well, has been neglected, and therefore in actual practice an ordinary well of between 20 and 25 per cent. less area would

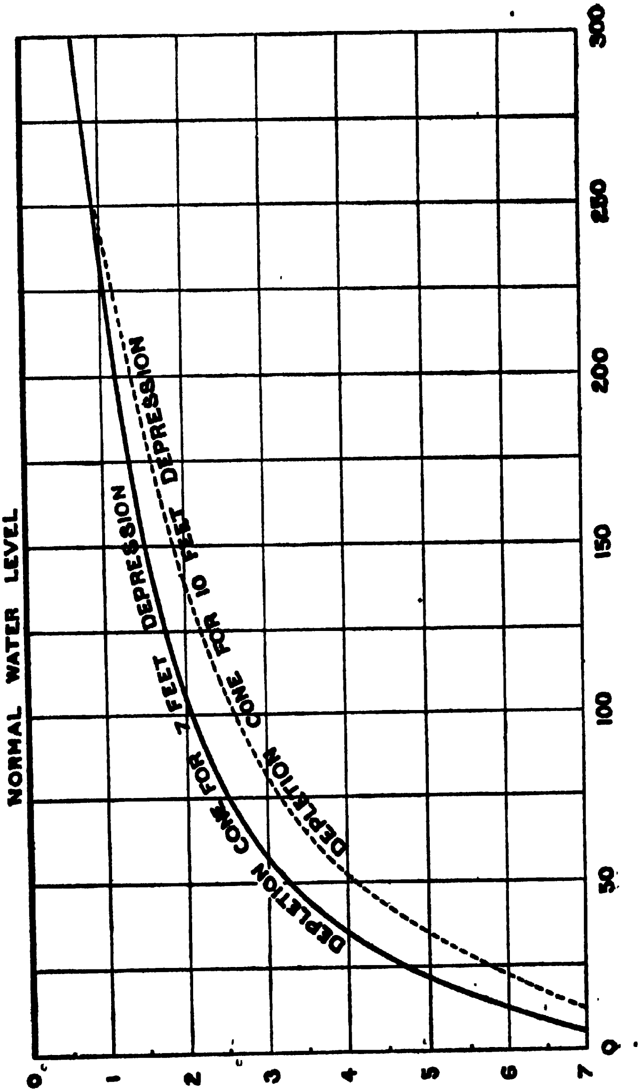
suffice to yield 45,000 gallons per hour; say a well of 54 feet diameter.

In estimating the yield from ordinary wells it is customary to allow a considerable margin, for example, although theoretically one large well of 54 feet diameter, or say 20 wells of 12 feet diameter, would yield the required supply, the larger well of 60½ feet or 25 of the smaller wells would in all probability be constructed (in actual practice several small wells would be sunk as that method would be less expensive than sinking the larger well), similarly in estimating the yield from the tube wells a margin of at least 25 per cent. should be allowed for. One advantage in sinking a tube well capable of yielding more than the required supply is that owing to a less quantity of water being taken than the tube is designed for, the water passes through the straining material at a correspondingly lower velocity and therefore the head which is causing the flow through the straining material is reduced, and a reduction of head means less expense for pumping. This reduction of head or withdrawal of less water than the tube well is designed for should not be carried to extremes, otherwise the upward velocity of water in the tube will be insufficient to hold the sand in suspension.

INFLUENCE ON WATER LEVEL.

The quantity of water which can be withdrawn from the subsoil, by a tube well, depends primarily on the texture of the subsoil; that is, on its ability to pass water through its pores or interstices under a reasonable pressure, and secondly on the superficial area of the soil over which the water is to be withdrawn. In other words, the working of a tube well is identical with the working of an ordinary well, in so far that a gravel stratum at the bottom of the ordinary well will pass a larger supply of water

Fig. 12.


NORMAL WATER LEVEL
DEPLETION CONE FOR 7 FEET DEPRESSION
DEPLETION CONE FOR 10 FEET DEPRESSION
0
50
100
150
200
250
300
0
1
2
3
4
5
6
7

than, say, a fine sandy clay, both being worked under the same head, and further, that in any one stratum, the superficial area has to be doubled if the discharge is to be doubled and the head kept constant. In tube wells, as with ordinary wells, a combination of these two principles affords a very considerable variation in discharge, and thus, by increasing the pressure or head, within limits, a considerable increase in discharge is obtained. When a head has been created by withdrawing water from a tube, the subsoil water surface curves back to approximately its original level, at some considerable distance from the tube well, and on stopping the pumping, the water rises to within a few inches of its original level in a very short time. Fig. 12 shows two curves of water depletion in the same subsoil. It will be observed that in the first hundred feet distance from the tube well the curve is very steep, but beyond that distance it generally flattens out, coming to within nine inches of its original level at a distance of approximately three hundred feet. Even in the case of the greater head, the curve joins the lesser head curve about two hundred and fifty feet from the tube. From three hundred feet to the point where the depletion curve merges into the normal water level is practically infinity. If therefore one foot of depression be neglected (and for all practical purposes this may be done), then small tube wells may be placed from five to six hundred feet from one another without any appreciable effect on the water level or power loss.

Unfortunately the writer has been unable to obtain a sufficiently large number of depletion cone levels, but, from observations made, it appears that after constantly working a tube well for some considerable time, the curve of the depletion cone gradually fattens out; the rate at which this takes place depending on the porosity of the subsoil. Punjab soils show a marked decrease

in the water surface curve in periods, varying from six months to two years.

It would seem reasonable to suppose that this flattening of the curve will continue until the cone of depletion coincides with the hydraulic gradient for the tube, excepting the slight curvature due to the combined effect of capillary attraction and gravity; the hydraulic gradient depending of course on the porosity of the subsoil and the velocity of the subsoil water flow. This flattening of the cone of the depletion curve means that there is a gradual diminution in the discharge from the tube, until the depletion curve assumes its staple gradient, due to the reduction in head in the immediate neighbourhood of the tube; for although the theoretical head remains constant, the horizontal distance which the water has to travel under this head is gradually increasing, and the friction offered to its passage through the subsoil corresponds to an actual loss of head—an increasing and measurable quantity. This point has to be taken into account in sinking tube wells from which a constant discharge is required, the subject being more fully dealt with under heading subsoil water in relation to tube wells on page 117.

LARGE DISCHARGES AND EXCESSIVE HEAD.

As stated above, the discharge from a tube well can be increased by increasing the draw down or head, within limits which depend on the porosity of the subsoil. If the critical velocity of the subsoil be exceeded, then a packing of the soil on the outside of the tube results, and the discharge is diminished, but assuming that the critical velocity of the subsoil is not being exceeded, the question arises, what is the economical discharge to take from a tube well in a particular soil? This resolves itself into a question of the subsoil water level only, and in districts where the subsoil water level is low, it is much more

economical to pump large discharges than in districts where the subsoil water is close to the ground surface.

Experiments carried out with Convoluted Tube Wells, discharging up to three cusecs, have shown that with this discharge the critical velocity of the subsoil was just exceeded, while at two and a half cusecs, the percolation velocity was well within the critical velocity. In this subsoil, which was a moderately fine sand, a discharge of two and a half cusecs was obtained under a depression head of sixteen feet nine inches, while a discharge of one and a quarter cusecs was obtained under a draw down of nine feet. When the critical velocity of the subsoil is not exceeded, the theoretical discharge of a tube varies directly as the head, and therefore a discharge of two and a half cusecs would be expected under a head of eighteen feet ; the fact that the discharge was obtained under a head fifteen inches less than this may be accounted for by slight errors in timing, or may be due to the velocity approaching the critical velocity of the subsoil and causing slight irregularities. The fact that the two and a half cusecs were obtained at a slightly less head than would be expected, supports the statement that when the subsoil water is close to the ground surface it is uneconomical to take large discharges from a tube well, for the following reasons.

Assume that the subsoil water level is ten feet below ground surface, and compare the power required to raise one and a quarter cusecs with the power required to raise two and a half cusecs.

For $1\frac{1}{4}$ cusecs, the total lift is :—

Water level	..	..	..	10 feet
Draw down	..	..	..	9 „
Friction	..	..	..	1·5 „
		Total head	..	$20\frac{1}{2}$ feet

For $2\frac{1}{2}$ cusecs, the total lift is :—

Water level	..	10 feet
Draw down	..	16·75 „
Friction	..	2 „
Total head	..	28·75 feet

The power required on the pump inlet for the smaller discharge is :—

$$\frac{468{\cdot}75 \times 10 \times 20{\cdot}5}{33{,}000} = 3{\cdot}063 \text{ H. P.}$$

while for the two and a half cusecs discharge the power at the pump inlet is :—

$$\frac{937{\cdot}5 \times 10 \times 28{\cdot}75}{33{,}000} = 8{\cdot}167 \text{ H. P.}$$

so that the actual power loss when pumping the larger supply is :—

$$8{\cdot}167 - 2\ (3{\cdot}063) = 2{\cdot}041 \text{ H. P.}$$

and, when average power plant is applied, the loss would be approximately 18 B. H. P.--13.5 B. H. P.=4.5 B. H. P so that in a working day of say twelve hours, 54 break horse power hours are absolutely lost, and therefore a large discharge on a low lift requires careful consideration before a scheme of this nature is embarked upon. In irrigation schemes, in particular, the maintenance charges are a first consideration.

In districts where the water level is some considerable depth below ground surface a large discharge becomes a much better paying investment. For example, assuming the subsoil water level at fifty feet below the ground surface, then for one and a quarter cusecs discharge the total lift is as follows :—

Water level	..	50 feet
Draw down	..	9 „
Friction	..	2·75 „
Total lift	..	61·75 feet

and for $2\frac{1}{2}$ cusecs, the total lift is :—

Water level	..	..	50 feet
Draw down	..	..	16·75 „
Friction	..	..	3·00 „
	Total lift	..	69·75 feet

The power required on the pump inlet for the smaller discharge is :—

$$\frac{468 \cdot 75 \times 10 \times 61 \cdot 75}{33{,}000} = 8 \cdot 771 \text{ H. P.}$$

and for the two and a half cusecs discharge the power is :—

$$\frac{937 \cdot 5 \times 10 \times 69 \cdot 75}{33{,}000} = 19 \cdot 815 \text{ H. P.}$$

The power loss in pumping the larger supply being :—

$$19 \cdot 815 - 2\,(8 \cdot 771) = 2 \cdot 273 \text{ H. P.}$$

so that with an average power plant the loss would be 43 B. H. P. – 38 B. H. P. = 5 B. H. P.

It is thus seen that in the deep lift the loss or waste in pumping amounts to 11·6 per cent., while in the lesser lift the loss is 25 per cent., and, therefore, it is only in cases of a very deep subsoil water level, where the interest on the initial cost of a single discharge tube well plant is less than the interest on the cost of two smaller plants by the working cost of the lost power, that a large discharge plant can be expected to be a financial success.

The above calculations are based on average conditions in the Punjab, and from subsoil observations elsewhere it may be sa d that they hold good for India generally. In the United States there are many districts where subsoil conditions are so favourable that discharges up to five cusecs are taken from depths of fifty and sixty feet on economical lines, but these conditions apparently do not exist, or at least are not general, in India.

TUBE WELLS FOR THE SMALL LANDHOLDER.

During the past six years, the development of tube wells in India for irrigation purposes has been chiefly in the direction of what one might term the large unit type; that is, tube wells capable of irrigating two to three hundred acres and upwards; one reason for this being that the demand has mainly been from proprietors who own large areas of land, and are desirous of having these irrigated as cheaply as possible; but the construction of a tube well irrigation plant, like most constructional works, does not mean that a plant for unit discharge is going to prove twice the cost of a plant for a half unit discharge, although, within the limits already referred to, most plants have been sunk for moderately large discharges. The consequence of this is that, until recently, little has been done for the small landholder, whose area is insufficient for the larger type of tube well, and who is unwilling to co-operate with his neighbours and have a tube well put down for the benefit of several holdings.

The Agricultural Department has put down many hundreds of small borings in ordinary irrigation wells for augmenting the supply in these, and this class of work has proved of considerable value in those districts where an impervious stratum is met with at a reasonable depth below the floor of the existing well, but in the many large tracts of the Punjab where no such impervious stratum exists this class of work could not be carried out.

In order to increase the water supply in wells in these districts, at a reasonable cost, the Department carried out experiments some eighteen months ago with a small size, modified, convoluted, tube well. The results of these experiments were so satisfactory, that during the past year, one hundred and sixty-three of these have been sunk, the area irrigated by each tube averaging ten acres, while the average cost complete has been under

Rs. 100 a well. For several months of the year, materials could not be obtained for the manufacture of these tube wells, and considering the current high price of metals it would appear that this class of work has a future before it.

IRRIGATION FROM CONVOLUTED TUBE WELLS BY PUMPING.*

Until electric power is distributed over areas uncommanded by Canal Irrigation, or over areas which have become water-logged, owing to excessive canal irrigation, and in which it is desired to stop or considerably reduce this system of irrigation and pump water from the subsoil, liquid fuel must be looked to as the source of power for such purposes.

Various schemes for harnessing the rivers of the Punjab have been prepared from time to time by prominent engineers, but owing to Eastern lack of enterprise those projects appear to have been indefinitely postponed.

From the data given in the projects, and from experience of hydro-electric schemes in other countries, there is not the slightest doubt that electrical energy can be supplied at consumers' terminals at a rate not exceeding one anna per horse power per hour.

That liquid fuel compares not unfavourably with this rate is well known, and experience has shown that oil engines, from six to over thirty horse power, can be run on ¾ pint low grade kerosine oil, per break horse power, per hour.

For purposes of calculation, one cusec of water raised thirty feet for twenty-four hours, will be taken as the unit, but it should be noted that if two cusecs

* I am deeply indebted to the Hon'ble Mr. J. T. Farrant, late Chief Engineer, Punjab, Public Works Department, for the valuable notes he so kindly supplied to me on this subject and on Irrigation by bullock-power.

were taken, then the original cost of pumping plant would be considerably less than double the cost of one cusec plant, consequently depreciation would be less, while attendance would remain the same for both plants. The horse power required to raise one cusec thirty feet is $\frac{\overset{\text{gallon.}}{6{\cdot}25} \times \overset{\text{lbs.}}{10} \times \overset{\text{secs.}}{60} \times \overset{\text{ft.}}{30}}{33{,}000 \text{ foot pounds}} = 3{\cdot}4$ nett h. p. and with an efficiency of 0·5 for engine and pump, the gross horse power would be 6·8.

The consumption of oil per day is 6·8 B.H.P. × 24 hrs. × 0·75 pint = 122·4 pints, and low grade kerosine oil can be purchased in bulk at 9·5 annas per gallon. The cost per day is therefore $\frac{\overset{\text{pints.}}{122{\cdot}4} \times \overset{\text{annas.}}{9{\cdot}5}}{16 \text{ annas} \times 8 \text{ pints}} =$ Rs. 9·084, adding Rs. 0·31 for lubricating oil, etc., and Rs. 0·581 for attention of a visiting driver at Rs. 18 per month for the one plant, then the total cost is Rs. 9·975, or say Rs. 10 per day of twenty-four hours.

With electric power at one anna per horse power per hour, and motor and pump efficiency of 0·55, the gross horse power is 6·2 and the daily cost $6{\cdot}2 \times 24 \times \frac{1}{16} =$ Rs. 9·3, *plus* 0·31 for lubrication and half the attention of visiting driver at Rs. 0·29, giving a total of Rs. 9·9, say Rs. 10 per day of twenty-four hours, in which 86,400 cubic feet of water is pumped.

As one acre contains 43,560 square feet, therefore the cost per acre foot is roughly Rs. 5.

Allowing 75 days for the sowing period of the Rabi crop, and five inches in depth for the first watering, and an efficiency factor of $\frac{5}{6}$ths which allows for $\frac{1}{6}$th loss by evaporation and absorption, then the area irrigated to a depth of five inches is $75 \times 2 \times \frac{12}{5} \times \frac{5}{6} = 300$ acres.

In the remaining 105 days of the Rabi crop period, 210 acre feet of water are delivered, of which $\frac{5}{6}$ths or 175 acre feet reach the fields, giving them an additional

depth of $\frac{175}{300} \times 12 = 7$ inches, or twelve inches in all; which is the amount required.

The cost of pumping for the Rabi crop is, therefore, first watering 75 days at Rs. 10=Rs. 750 for 300 acres, or Rs. 2·5 per acre.

Subsequent waterings 105 days at Rs. 10=Rs. 1,050 for 300 acres, or Rs. 3·5 per acre.

The total cost per acre being Rs. 6.

For the Kharif crop a total depth of two feet of water is required, and the total crop period being 180 days the area which can be irrigated with an efficiency of $\frac{5}{8}$ths is $180 \times 2 \times \frac{5}{8} \times \frac{1}{2} = 150$ acres. Allowing the first watering six inches deep, the period is 45 days, and the cost $45 \times 10 =$ Rs. 450 for 150 acres, or Rs. 3 per acre.

In the remaining 135 days the waterings amount to a depth of eighteen inches, and the cost is $135 \times 10 =$ Rs. 1,350, or 150 acres at Rs. 9 per acre.

The total cost per acre being Rs. 12.

The annual cost is, therefore, Rabi 300 acres at Rs. 6 per acre=Rs. 1,800, Kharif 150 acres at Rs. 12 per acre= Rs. 1,800, being a total of 450 acres irrigated annually for Rs. 3,600, or an average of Rs. 8 per acre per annum.

A tube well of one cusec delivery, irrigating 450 acres annually, or say 70 per cent. of its commanded area, is sufficient for 640 acres, or one square mile.

The estimated cost of the entire pumping plant is as follows :—

	Rs.†
*Convoluted tube well of 1·25 cusec capacity ..	1,300
Sinking charges	350
Direct coupled oil engine and pump, erected complete	3,450
Engine house	700
Distributing tank, etc.	200
Total ..	6,000

* For subsoils of low porosity a 1·25 cusec tube is allowed.

† One rupee is equal to one shilling and four pence, sterling, *i.e.*, Rs. 15=£1.

The annual recurring charges would be :—

		Rs.
Interest on Rs. 6,000 at 4 per cent.	..	240
Depreciation of plant at 5 per cent.	..	300
Power, including attention as above	..	3,600
Collection of dues (allow one patwari for two square miles)	..	135
Total	..	4,275

The average rate which can be charged is, therefore, Rs. 9-8 per acre per annum.

REVISED RATES.

Prices have altered considerably during the last few years on account of the war, and therefore the preceding figures are no longer reliable. Tube-well irrigation plants ranging from one and a half to two cusecs capacity, in areas where subsoil water level is from twenty to thirty feet deep, give the following results :—

	Rs.
Cost of complete installation, including tube well, plain pipes, vertical spindle turbine pump, crude oil engine, engine house, delivery chamber, and all masonry work and fittings..	20,000

Running Costs

Per day of 16 hours.

		Rs.	A.
Fuel crude oil 250 pounds @ Rs. 85 ton, say	..	9	8
Driver at Rs. 50 p.m., asstt. @ Rs. 25	..	2	8
Lubricating oil, waste, etc., sundries	..	1	8
Total daily cost	..	13	8

Annual Maintenance.

		Rs.
Interest on capital of Rs. 20,000 @ 7½%	..	1,500
Depreciation of whole plant @ 7½%	..	1,500
Driving charges for 280 days @ Rs. 13-8	..	3,780
Pay of drivers when plant is idle. 85 @ Rs. 2-8	..	213
Annual repairs to plant ..	..	207
Total	..	7,200

Irrigation.

Plant is capable of irrigating seven acres per day of 16 hours to a depth of three inches. If waterings are given at intervals of 20 days during the hot weather or Kharif crop, and at intervals of 30 days during the cold weather or Rabi crop, then the area cropped per annum is as follows :—

Hot weather (Kharif) crop.	7 × 20	=	140 acres.
Cold weather (Rabi) crop.	7 × 30	=	210 ,,
Total	..		350 acres.

An area of 350 acres cropped at an initial cost of Rs. 7,200, or an average cost of Rs. 20-9 per acre per crop. Kharif crop costing Rs. 26 per acre and Rabi crop costing Rs. 17 per acre.

Irrigation by Bullock Power from Ordinary Wells.

The power exerted by bullocks has a definite relationship to the animal weight. Dynamometer tests in a number of cases show that external work at the rate of 560 foot pounds per hour per pound weight of animal over a period of eight hours is the maximum amount of work obtainable. That is, an average bullock, weighing 900 pounds, is capable of 8,400 foot pounds external work, or say one-fourth horse power of 33,000 foot pounds per minute.

On an average lift of 25 feet, two bullocks will lift one-tenth cusec water, *i.e.*, 2,250 gallons per hour, $=\frac{37\cdot5\times25\times10}{33,000}=0\cdot28$. Two bullocks of 900 pounds being equal to 0·5 horse power, 0·22 horse power being absorbed in lifting mechanism, *i.e.*, frictional losses, which in ordinary bullock gear, vary from 45 to 60 per cent.

Two pairs of bullocks working in shifts for 16 hours per day, lifting one-tenth cusec, a height of

25 feet, will irrigate half an acre. $\frac{6\times60\times16\times4}{43,560}=0\cdot5$ acre per day.

Irrigation at 20 days intervals for Kharif, $= 20 \times 0\cdot5 =$ 10 acres.
Irrigation at 30 days intervals for Rabi, $= 30 \times 0\cdot5 =$ 15 acres.

Cost of plant.

		Rs.
Two pairs of bullocks at Rs. 200 ..	..	400
Cost of well and gearing ..	..	750
Total cost	..	1,150

Annual maintenance.

	Rs.
Two pairs of bullocks at Rs. 22 per mensem per pair	528
Interest on capital of Rs. 1,150 at 7½ per cent. ..	86
Depreciation of well and gear Rs. 750 at 10 per cent.	75
Depreciation of bullocks Rs. 400 at 15 per cent.	60
Total	749

Area cropped per annum is 25 acres at a cost of Rs. 749 or average cost of Rs. 30 per acre approximately.

The cost of the Rabi crop being 15 acres at a cost of Rs. $\frac{749}{2}$ = Rs. 25 per acre.

The cost of the Kharif crop being 10 acres at a cost of Rs. $\frac{749}{2}$ = Rs. 37 per acre.

With current high prices for machinery, etc., power installations are cheaper than bullock power by approximately 33 per cent. On greater lifts the saving is more marked.

TUBE WELLS AS A SOURCE OF PUBLIC WATER-SUPPLY.

FROM A PAPER READ AT SECOND ALL-INDIA SANITARY CONFERENCE, MADRAS, 1912.

IT is unnecessary for me to enter into details of the inadequate and contaminated state of the water supplies of many of the towns and villages in India. Every

sanitarian knows the necessity of a pure water-supply, if the health of the people is to be improved.

In order to provide a supply of good water, the wells require to be situated on land free from surface contamination and therefore at some considerable distance from the village, the water being pumped from the wells and delivered to an elevated tank centrally situated in the village, or to ordinary standposts.

A scheme of this type is somewhat costly, necessitating as it does, wells probably 60 to 70 feet in depth, a length of at least half a mile of delivery pipe from the wells to the village, and a higher powered engine to overcome the friction in this half mile of pipe.

For villages or small towns where the subsoil water level is within 20 feet of ground surface, the initial cost of a water scheme of this nature would roughly be Rs. 7 per head of population, and the annual maintenance including depreciation and interest 15·47 annas per head of population. Statement " A," page 53, shows how these figures have been arrived at, and although calculated on a supply for a town of 6,000 inhabitants, they are approximately correct for populations between 1,000 and 10,000.

Statement " B," page 54, shows the initial cost of a scheme for supplying this village with the same quantity of water from tube wells ; this comes to Rs. 3 per head of population, showing a reduction of 56 per cent. in favour of the tube well scheme. The annual maintenance amounts to 10·2 annas per head of population, being a saving of 33 per cent. over the supply from ordinary wells.

This difference in initial and recurring cost between the two schemes is due to the fact that one medium sized tube well is capable of supplying all the water required, and it can be sunk in the village below

contamination level, effecting a further saving of the half mile of rising main and in the engine power required to overcome the friction in this main.

These savings in initial cost effect the saving of 33 per cent. in annual maintenance as shown in Statement " B," page 54.

Although the tube wells are estimated to last from 15 to 20 years, no actual test has been made of their lasting capabilities and therefore depreciation at the rate of 20 per cent. has been allowed on the cost of the tube wells, including sinking and necessary masonry work. This permits of the tubes being withdrawn and new ones sunk every five years. It is most unlikely that this sinking fund will require to be utilized, but even if utilized the tube well scheme is still very substantially cheaper both in initial and in recurring cost than the ordinary well supply.

These figures are, I think, sufficient justification for the installation of a tube well water-supply in these towns and villages where the initial and recurring cost of an ordinary well water-supply scheme is prohibitive.

Generally speaking, tube wells may be successfully adopted in any district in which a supply of water is obtainable from ordinary wells; with an average water bearing subsoil, the yield of the tube wells, manufactured by the Empire Engineering Co., Ltd., Cawnpore, varies from 5,000 gallons per hour in the 3½-inch tube to 45,000 gallons per hour in the 9-inch size.

The question of the relative cost of tube wells is of no great importance, when one considers that from an ordinary masonry well twelve feet in diameter as built for modern water supplies, the average yield is roughly 3,000 gallons per hour, and the cost is over £200; whereas, at a less cost a tube well can be sunk which will yield 45,000 gallons per hour or 15 times the supply of an ordinary well and under the same head.

STATEMENT "A."

Rough estimate of cost of a water-supply from Ordinary Wells for a village of 6,000 inhabitants.

Population 6,000 at 15 gallons per head per day = 90,000 gallons, to be pumped in 8 hours = 11,250 gallons per hour, say 190 gallons per minute.

Average wells of 12 feet in diameter may be expected to yield 3,000 gallons per hour, therefore 4 wells are required.

Estimate of cost of scheme.

	Rs.*
Land for 4 wells and engine house 750′×150′= say $2\frac{1}{2}$ acres at Rs. 2,000 per acre ..	5,000
Wells 12 feet diameter 65 feet deep. No. 4, at Rs. 3,500 each	14,000
Suction main 8 inches diameter laid and joined complete, 550 feet at Rs. 3-11-0 per foot, say	2,000
Rising main 6 inches diameter laid and joined complete, 2,640 feet at Rs. 2-6-0 per foot, say	6,300
Engine house 20′ × 12′, plinth, say 350 square feet at Rs. 2-4-0 per square foot, say ..	800
Engine and pump to lift 22 feet and force 25 feet, with friction of 13·8 feet in 2,640 feet of rising main, and 3 feet in bends, etc., say 64 feet. H. P. = (190 × 10 × 64) ÷ 33,000 = 3·68 with 0·5 efficiency = 7·36, say 8 B. H. P. No. 2 complete at Rs. 4,000 each ..	8,000
Elevated tank centrally situated in village with all necessary fittings, allow	6,000
Total cost ..	42,100

Maintenance of this scheme.

	Rs.	A.	P.
Oil consumption (8 × 0·75 × 8) ÷ 8 = 6 gallons at $9\frac{1}{2}$ annas	3	9	0
Lubricating oil	0	5	6
Waste and sundry small stores	0	3	6
Starting oil	0	2	0
Driver at Rs. 30 per month	1	0	0
Daily running cqst ..	5	4	0

* One rupee is equal to one shilling and four pence sterling, *i.e.*, Rs. 15=£1.

Annual maintenance

		Rs.
Driving cost Rs. 5-4-0 × 356 = 1,917, say	..	1,920
Interest on Rs. 42,100 at 4 per cent.	..	1,684
Depreciation on Rs. 42,100 at 5 per cent.	..	2,105
Total	..	5,700
Allowing for collection and sundries, say	..	5,800

STATEMENT "B."

Rough estimate of cost of a water-supply from Tube Wells for a village of 6,000 inhabitants.

Population of 6,000 at 15 gallons per head per day = 90,000 gallons, to be pumped in 8 hours = 11,250 gallons per hour, say 190 gallons per minute.

One 5-inch convoluted tube well will deliver 11,250 gallons per hour, but allow for the tubes being in duplicate.

Estimate of cost of scheme.

		Rs.
Land in village for engine house and tube wells allow 40′ × 12′, or plinth area of 700 square feet	..	100
Convoluted tube well 5 inches diameter, sunk, complete with masonry chambers, etc. No. 2, at Rs. 1,500	..	3,000
Suction main and fittings 140 feet at Rs. 3 per foot	..	420
Rising Main and fittings 100 feet at Rs. 2-6-0 per foot, say	..	240
Engine house, allow 700 square feet at Rs. 2-4-0 per square foot, say	..	1,600
Engine and pump to lift 22 feet and force 25 feet with 3 feet friction, total lift = 50 feet H. P. = (190 × 10 × 50) ÷ 33,000 = 2·88, efficiency 0·5 = 5·76, say 6 B. H. P. No. 2, at Rs. 3,500	..	7,000
Elevated tank, centrally situated in village with all necessary fittings, allow	..	6,000
Total cost ..	..	18,360

Maintenance of this scheme.

	Rs.	A.	P.
Oil consumption $(6 \times 0{\cdot}75 \times 8) \div 8 = 4{\cdot}5$ gallons at 9½ annas	2	10	9
Lubricating oil	0	4	6
Waste and sundry small stores	0	3	3
Starting oil	0	2	0
Driver at Rs. 30 per month	1	0	0
Daily driving cost ..	4	4	6

Annual maintenance.

	Rs.
Driving cost Rs. 4-4-6 × 365 = 1,562, say ..	1,600
Interest on Rs. 18,360 at 4 per cent., say ..	734
Depreciation on tubes Rs. 3,000 at 20 per cent.	600
Depreciation on remainder of plant, Rs. 15,360 at 5 per cent.	768
Total ..	3,702
Allowing for collection and sundries, say ..	3,800

NOTE—Prices in 1920 are approximately double those given above.

VARIOUS METHODS OF BORING.

THE convoluted tube well, like all other tube wells for large discharges, requires to be inserted in a bore hole. There are several methods of sinking the boring tube, all of which have their special advantages, but perhaps the simplest method is a modification of the Chinese system known as the Rope system.

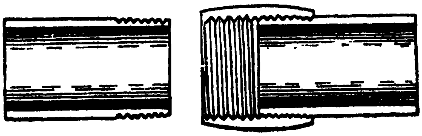
ROPE SYSTEM OF BORING.

Boring tubes.

HAVING selected the size of convoluted tube well required, a boring tube should be procured, and if this is being purchased with a view to using it for several tube wells, it is recommended that a large size bore tube be procured, 12 or 15 inches diameter, as this latter size will take the largest convoluted tube well made, and can be sunk up to three or four hundred feet at practically the same cost as a seven or nine inch bore tube. It

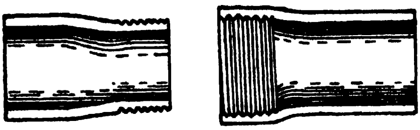
should be noted that the diameter of bore tubes refer to external diameter and not to internal diameter as in ordinary pipes and tubes. The most convenient lengths for these tubes is ten feet, otherwise high and excessively heavy derricks are required for handling the pipes, if the standard lengths of 17 to 25 feet are used. For general all-round work the socket joint with long bevelled socket will be found most suitable. See Fig. 13.

No. 1.



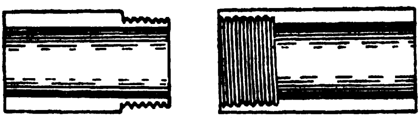
Socket Joint.

No. 2.



Swelled and Cressed.

No. 3.



Flush Joint.

Fig. 13.

This form of joint is recommended on account of the strength, although the outside collar offers considerable resistance in sinking. The author has frequently used the swelled and cressed joints, No. 2 on Plate, and these are quite satisfactory for borings up to 200 feet in sandy soils, but in stiff soils where driving or twisting of the tubes may be necessary the sockets are liable to fail by bursting, and if these joints are to be used in stiff soils a

lock ring should first be screwed on the spigot or cressed end of the pipe, so that the socket end of the next pipe will butt against this ring, when screwed up. It has been proved that this ring increases the strength of the joint by 50 per cent.

Joint No. 3. Fig. 13, has the advantage of offering no resistance externally to the sinking of the tubes and of having the full internal bore at the joint, but it necessitates the tubes being of thicker metal to allow of the joint being made and a finer screw which is difficult to start and liable to damage; tubes with these joints frequently give way at the joint shoulder, and it is practically impossible to recess and rescrew the damaged tube at the site of the boring. These tubes are known as the Artesian well bore steel tubes and can be obtained of different weights; for borings up to two or three hundred feet deep a medium thickness of metal will be found sufficient and will last for a large number of borings. With regard to the total length of boring tube required, this depends largely on the depth of water below ground surface; tubing sufficient to sink from ground surface to 120 feet below normal water-level will be required, and it is advisable to have a spare ten feet length or two, so that after the tubes have been in use for some time and the joints become damaged or worn, a few inches can be cut from the ends of the tubes and the joints remade.

Cutting Shoe.

In order to render the sinking of the bore tube as easy as possible and to protect the lower edge of the bore tube from damage, a cutting shoe should be used. There are two types of shoes and each has its special advantage. No. 1, Fig. 14 shows the slip type and No. 2, Fig. 14, shows the screw type, both shoes are made from tempered steel and are slightly splayed out at the cutting edge, being approximately one inch greater diameter at the cutting

edge than the external diameter of the bore tube. The screw type of shoe is chiefly used for sandy soils and

No. 1. No. 2.

Slip Shoe Screw Shoe

FIG. 14.

where the boring does not exceed two to three hundred feet. These soils do not offer much additional friction to withdrawal of the bore tube with the screwed shoe attached, but in stiff clay, rock soils, and for deep borings, the slip shoe is a decided advantage as the shoe clears a hole slightly larger than the bore tube, and this clearance remains open to some extent, thus friction on the tube is reduced both in sinking and in withdrawal; this type of shoe is, as its name implies, slipped from the bore tube and left at the bottom of the bore when the tube is withdrawn. The cutting shoes are not expensive and the cost of one shoe per boring is amply repaid in the reduced cost of sinking the bore tube.

Starting boring. The simplest method of starting the bore is to dig a hole eight or ten feet deep keeping it as small in diameter as convenient, into this hole the first length of bore tube is lowered, having the cutting shoe at the bottom, the bore tube is carefully plumbed and the hole filled up with earth well rammed to hold the bore tube in position. When the boring is to be a deep one it is advisable to sink a much deeper hole for a start, at least 30 feet, and a timber casing is put in this hole,

Details of Wood Clamp.

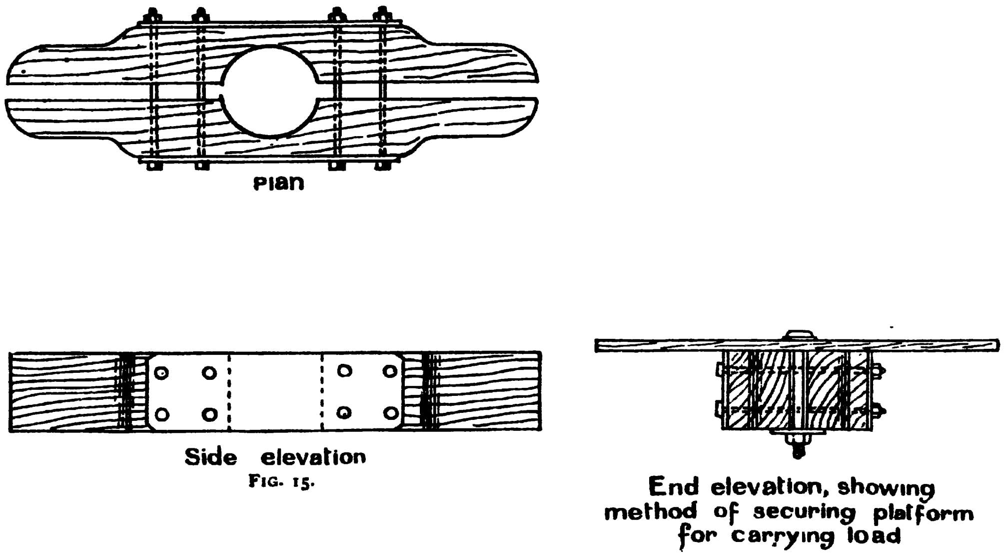


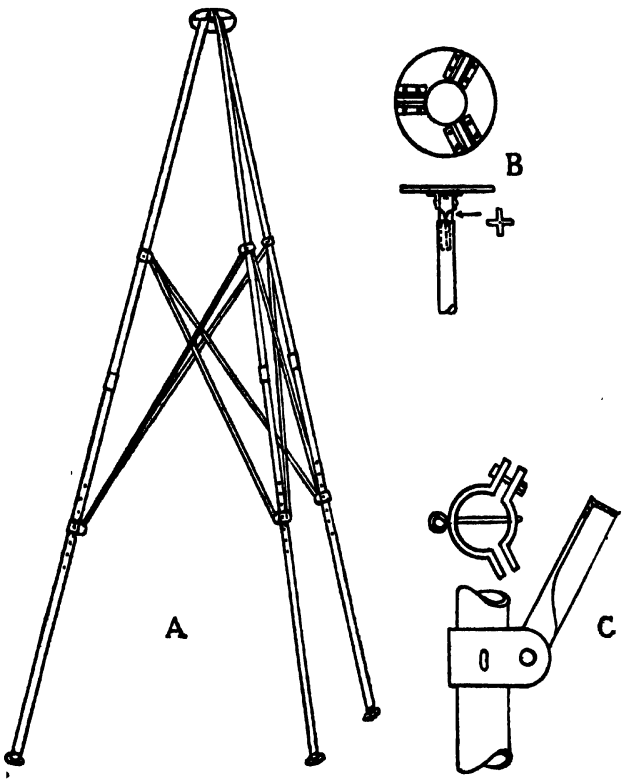
FIG. 15.

the casing carrying guides for the bore tube. Great care should be exercised in plumbing the bore tubes for deep borings, the maximum variation being not over one quarter of an inch in the 30 feet depth. The second length of bore tube is now screwed to the first length and on to this the wood clamp, Fig. 15, is secured about five feet above ground level. The wood platforms for carrying the load should be bolted on to the clamp and loaded with sandbags or preferably rail cuttings. It is a convenience if a timber platform is placed on the ground having a hole cut in it through which the bore tube sinks, this in addition to acting as a guide for the bore tube, affords a sound footing for the workmen and a bearing for screw or hydraulic jacks, etc.

Tripod or derrick.

The tripod should now be erected over the boring tube in such a position that a rope hanging from the single sheave pulley is centrally over the bore tube. A simple form of tripod or shear legs, Fig. 16, is made up from four inches diameter wrought iron pipes and the length of legs should be about 25 feet. Flange feet are more convenient than spiked feet, as the latter are liable to sink in soft ground, while the former can be bedded firmly on any sort of ground. The cross struts may be made from one and a half inch by one and a half inch L iron and the lower collars to which these struts are bolted are free to slide up and down the tube, being fixed in position by passing a half inch steel pin through the collar and into one of the six holes drilled in the pipe for the purpose. This arrangement besides allowing of the tripod being easily plumbed over the bore tube, allows of it being closed up umbrella-wise for transport. The join at the apex of the tripod is made from a circular piece of three-fourth inch iron plate 15 inches in diameter, from the centre of which a circular hole of five inches diameter is cut, the legs are hinged to this

ring as shewn in the drawing (B. Fig. 16). The filling piece at the upper end of each leg, which joins the half hinge, might be made from a casting entirely fitting the pipe, but the construction shewn from a piece of cruciform steel has been found more convenient and lighter for transport. The single sheave pulley is suspended from the apex of tripod by hanging the pully on a short length of one inch bar and resting the bar on the ring plate.



(A) Derrick complete. (B) Deals of top joint.
(C) Details of siding collar
***Note*—Illustrations show only one bolt in collar.**
Fig. 16.

A good hemp rope of two and a half to three inches circumference and about 100 feet longer than the proposed total depth of the bore hole is required, one end of this should be passed over the single sheave pully and spliced round the swivel end of a boring rod. Fig. 17 shows a fairly complete set of boring tools, and it is most improbable that all of these will be required; for borings up to 300 feet deep, tools of the six and a half inch or eight inch size will be sufficient unless a considerable depth of rock is to be bored, in which case one or two chisels of the size of the bore tube should be obtained. A complete set of boring rods sufficient to reach to the bottom of the bore hole should also be obtained, these are made up in ten feet lengths, and a suitable section is the square rod of one and a half inch side; although the boring is being made with a rope these rods are a necessity if the rope should break; leaving the boring tool and a length of rope in the bore hole.

Boring tools.

It now depends on the nature of the soil which tool is required for boring; if the soil is sand or clay, then the sludging tool or sand pump should be attached to the swivel head and lowered to the bottom of the bore tube; by raising this tool a few feet and allowing it to drop, the sand or clay is driven into the tool and prevented from dropping out by the flap valve. This operation performed several times should suffice to fill the sludging tool; it should then be withdrawn, emptied, and the operation repeated. If on withdrawal of the sludger little or no material is found in it, the reason may be that the soil is too stiff for the material to get past the valve on each stroke; by pouring water into the bore hole from time to time this difficulty may be overcome, or, in addition, a ten feet length of boring rod may be interposed between the sludging tool and the swivel head, this additional weight

Use of boring tools.

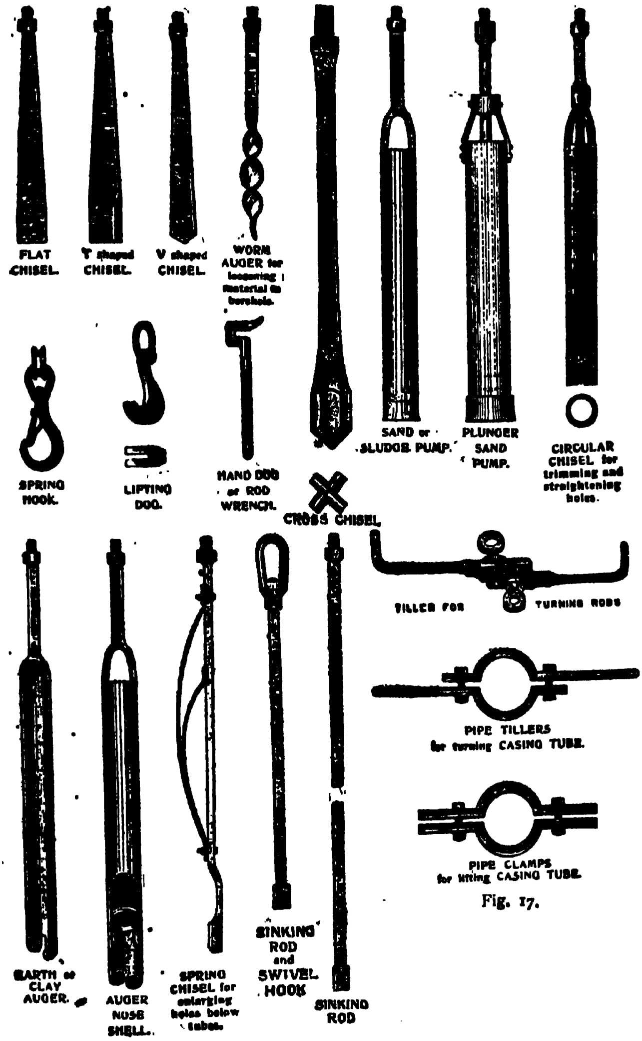

FLAT CHISEL.
T shaped CHISEL.
V shaped CHISEL.
WORM AUGER for loosening material in borehole.
SAND or SLUDGE PUMP.
PLUNGER SAND PUMP.
CIRCULAR CHISEL for trimming and straightening holes.
SPRING HOOK.
LIFTING DOG.
HAND DOG or ROD WRENCH.
CROSS CHISEL
TILLER FOR TURNING RODS
PIPE TILLERS for turning CASING TUBE.
PIPE CLAMPS for lifting CASING TUBE.
EARTH or CLAY AUGER.
AUGER NOSE SHELL.
SPRING CHISEL for enlarging holes below tubes.
SINKING ROD and SWIVEL HOOK
SINKING ROD

Fig. 17.

will carry the sludging tool into moderately stiff clay. As the boring operation continues the bore tube is pressed down by the load on it, until the wood clamp carrying the load rests on the heads of two hydraulic or screw jacks, placed on the timber platform on the ground.

The bolts of the wood clamp are then loosened and the clamp with its load " jacked up " three or four feet and again securely clamped to the bore tube. Care should be taken that the load on the wood clamp is well balanced, or on loosening the clamp bolts the clamp may tilt slightly and upset part of the load, may be causing serious injury to workmen. The clamp may be unloaded after every five feet of sinking and raised by hand and again loaded, but this operation is extremely slow, particularly after the boring has reached a depth of 100 or 150 feet and the load may be as much as ten tons, with proper care the load can be " jacked up " from time to time throughout the entire boring, only additional load being added as found necessary to carry the bore tube down.

If clay or rock is met with which cannot be bored with the sludging tool, then the sludging tool should be changed for a straight or cross chisel ; this tool is used in an exactly similar manner to the sludging tool and its function is to break up the hard subsoil ; when a sufficient depth has been broken, the sludging tool is again employed to pick up the broken material. In boring through hard material the enlarging tool should be frequently used. This tool bores out the hole a trifle larger than the bore tube, the spring loop on one side of the tool shank presses on one side of the bore tube, while the tool point works under the cutting shoe, at the opposite side. This tool and also the chisels should be given a turn of 20 to 30 degrees every stroke to prevent them from becoming wedged in their own cut. It frequently happens in boring that the bore tube comes " square " or partly

on to a boulder; if the boulder is large it can be bored like ordinary rock, but if small it has to be broken up carefully, and for this purpose the cross chisel will be found most useful. The sludging tool, straight chisel, tee chisel, and cross chisel, will generally be found sufficient for most borings; the writer has never used the so-called enlarging tool, but by "upsetting" the shank of an ordinary tee chisel in such a way that the tool is turned off the centre line of the boring rod, all hard material can be bored easily from under the cutting shoe.

ROD BORING.

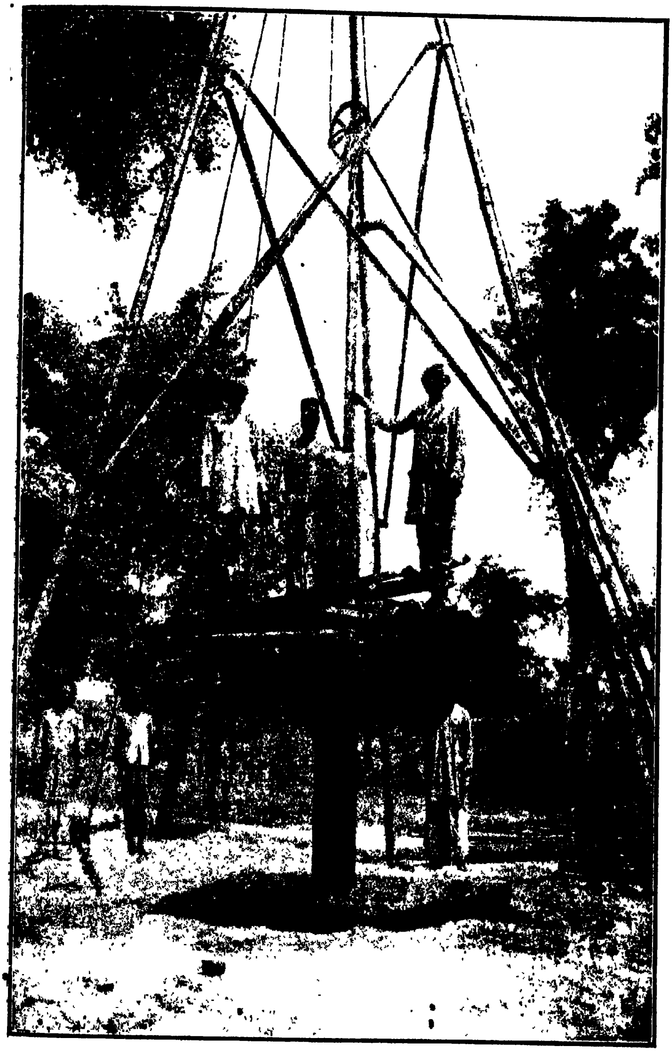
THE sinking of bore holes with rods extending from ground surface to the tool is carried out in exactly the same manner as the rope system. The rods can be obtained made of ash wood, with the metal male and female screws spliced on, but generally steel rods as described above are employed. The objection to this system of boring is the waste of time in withdrawing and lowering the tools, as the tool can only be raised ten feet at a time, one length of rod unscrewed, then the tool raised the second ten feet and the second length of rod unscrewed, and so on; similarly the lowering of the tool is a very tedious process. When the bore hole has reached a depth of 150 feet, the weight of the rods becomes greater than can be comfortably worked by a gang of men pulling and releasing on the rope attached to the swivel head and which passes over the single sheave pulley as in rope boring. The rods for medium depths of bores are most conveniently worked by a walking beam erected at ground surface; the beam is arranged as a lever, a load is applied at one end to almost balance the weight of the rods and reciprocating motion is imparted to the tool by the workmen stepping on and off the loaded end of the beam, or in deep borings the walking beam is operated by a crank connected to a

steam or other engine. In order to obviate the jarring effect of the great length of rods, particularly in very deep borings when steam or other power is used to operate the rods, a trip link is introduced 20 or 30 feet above the tool; this consists of a telescopic rod arranged with a very ingenious system of clutches which allows of the tool and the length of rod below the trip link, dropping independently of the length of rod above the trip link, this arrangement also prevents the tool becoming wedged in hard subsoil or rock on account of being over-driven and also minimises the chances of broken rods due to fatigue and consequent crystallization of structure owing to constant vibration.

WATER JET BORING.

In water jet boring the tripod and the starting of the bore tube is the same as for the methods already described. From the pulley of the tripod a length of $3\frac{1}{2}$ inches diameter ordinary W. I. pipe is suspended within the bore tube, this tube is fitted with a nozzle at its lower end, gradually tapering to an orifice of $1\frac{1}{4}$ inches diameter, the nozzle is kept about six inches above the bottom of the bore hole and a suitable connection with a steam or other power pump having been made at the upper end of the pipe, water is pumped into the bore hole. The effect of the water jet impinging on the bottom of the bore hole is to loosen and break up the subsoil which is washed out of the bore tube by the upward current of water; as the subsoil is washed out, the bore tube sinks and the $3\frac{1}{2}$-inch jet pipe is lowered to maintain a distance of a few inches only between the nozzle and the bottom of the boring.

This system of boring is extremely expeditious in sand, clay or other soft subsoils, and even in soft or rotten rock or kankar, it is quite satisfactory if a steel spike is secured to the nozzle and the jet pipe used



Sinking 12-inch boring tube by water jet system, subsoil is broken up and washed out by the water overflowing at mouth of bore tube

as a jumper to break up these materials which are then washed out by the jet. For borings which are mostly in rock, hollow chisels of various cross sections can be obtained, this form of tool allows of its use in combination with the water jet. The writer has sunk a large number of borings in Northern India by this system of water jet and with 12-inch boring tubes in sand, sandy clay and clay with a stratum of two to three feet of kankar the average rate of progress is 15 feet per day or practically double the rate of progress with the ordinary sand pump or sludging tool. The power of pump should not be less than 150 gallons per minute, and an extremely suitable make for this work is the portable steam fire engine of this capacity, built by Messrs. Merryweather & Co. The pump is connected to the upper end of the jet pipe by a fire hose, a tee piece being fitted to the upper end of the jet pipe and the hose coupled to the tee ; the upper end of the tee is provided with a screwed plug fitted with a swivel hook for suspending from the block of tripod ; frontispiece also plate facing page 67 and Fig. 18 show all the details of this system of boring.

BORING WITH MARTIN'S SLUDGER.

This system is practically the reverse of the water jet system of boring. A cross or S chisel is attached to the lower end of the jet pipe, in place of the nozzle, and the sludger is screwed to the upper end of the pipe and secured to the rope passing over the pulley of the tripod. A reciprocating motion is given to the boring tools and a liberal supply of water poured frequently into the bore tube. The sand or other material forming the subsoil is pumped out along with the water through the pipe and sludger. The advantage of this, like the water jet system, is that the boring process is continuous and the tool does not require to be withdrawn until the

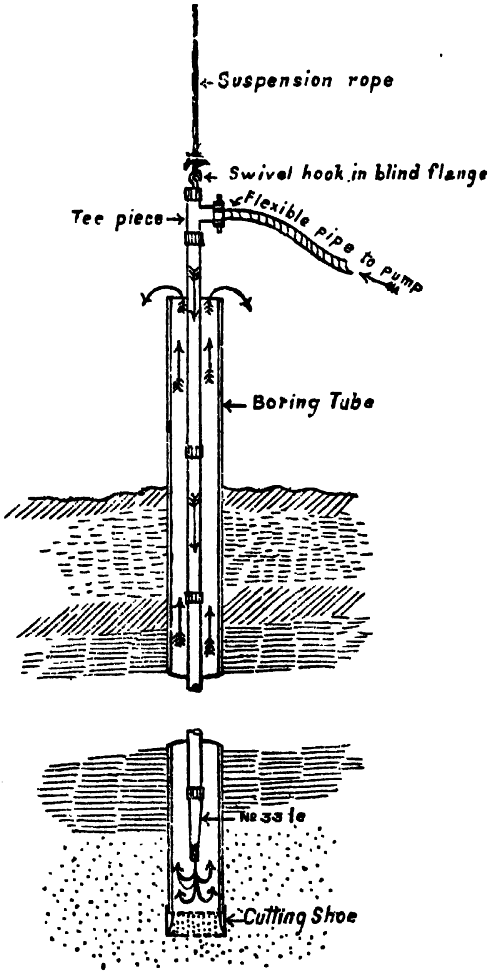


Fig. 18. {Diagram of water jet system of boring.
Arrows show direction of flow of water.

full depth of boring is reached. The length of stroke of the boring tool should be about three feet, and downward stroke must be smart. The water supply to the bore or casing tube should be plentiful and the closer the sludging tool is to the water level the better will be the results as the sludger works best with a medium suction lift. Fig. 19 shows the general arrangement for this system of boring.

CORE BORING.

THIS system is most generally used for deep borings in rock and prospecting work where accurate samples of the rocks traversed are required. As its name implies this system preserves the core intact and an absolutely accurate geological section showing the exact depth and inclination of each stratum can be prepared.

The working part of the drill consists of the so-called crown, which is a short piece of cast steel tube, into one end of this tube a number of black diamonds are fastened. The upper end of this cast steel tube or crown is secured to steel pipes which take the place of boring rods. Machinery at ground surface cause the pipes and crown to rotate, the diamond studded edge of the latter making an annular cut in the solid rock leaving a core, which breaking off from time to time is caught by an internal shoulder in the crown and brought to the surface when the tool is raised at intervals. The detritus is washed out by a constant stream of water being pumped down the hollow rod or pipe and returning to ground surface between the outside of the steel pipe and the bore hole.

With this system, boring can be carried on continuously at a speed quite unattainable by any of the methods above described. A recent improvement in the diamond drill is the fixing of diamonds in the crown. At one time diamonds were set direct into the crown and an expert

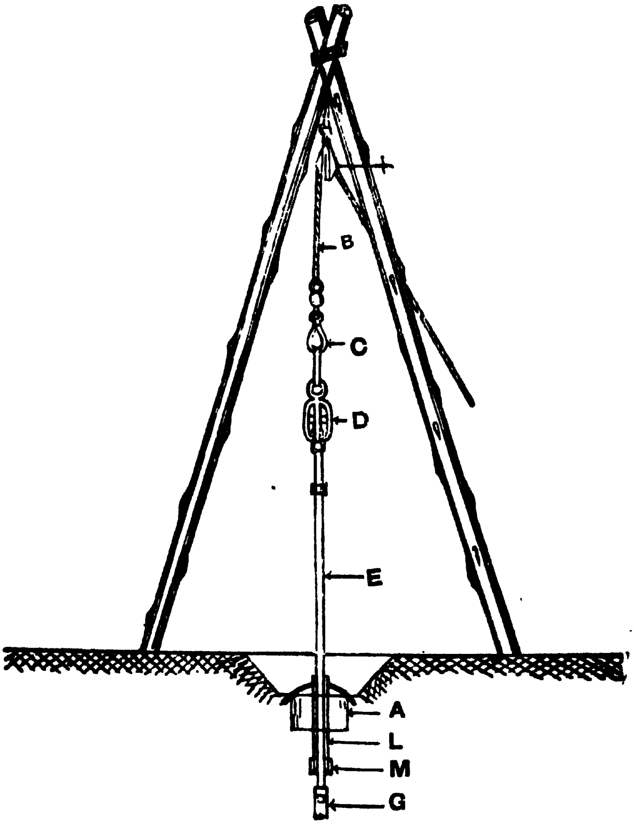


Fig. 19.—(B) Sinking rope. (C) Swivel hook. (D) Martin's sludger. (E) Boring rod which is hollow in this case. (A) Guide drum. (L) Casing or boring tube. (M) Cutting shoe. (G) Boring tool.

diamond setter was required at the site of the boring operation; now each diamond is secured in a small steel plate and when a diamond is lost or requires resetting, etc., the plate is unscrewed from the crown and a fresh plate and diamond substituted. The Calyx system of boring is in general principle the same as above, but in place of a diamond studded crown, a crown fitted with steel balls or cutters is used.

Core boring can be carried out expeditiously and without trouble to depths frequently over 3,000 feet.

BORING IN WELLS.

WHEN a convoluted tube well is to be used for augmenting the supply of an existing well or in a new well which may be necessary as a sump for placing a pump within suction range of the water surface, the procedure is as follows:—The well should be covered over with a timber platform in which a hole is cut large enough for the boring tube to slip through; several lengths of boring tube are screwed together and passed through the hole in the platform until the lower end of the boring tube fitted with its cutting shoe, rests on the bottom or floor of the well, the upper end of the boring tube projecting several feet above the platform. The wood clamp for carrying the load is secured to the boring tube a few feet above the platform, the load applied, and boring by any of the described methods is then commenced.

COMMON ACCIDENTS IN BORING.

Broken cables.

IN boring by the rope system one of the most frequent accidents is breakage of the cable; when this happens a new string of tools has to be prepared consisting of the swivel hook or rope socket, a length of iron boring rod to act

as a weight or sinking bar, a trip link which allows of the tool being jerked or jarred upwards and a rope "spear" or "grab." The latter is simply a two or three-pronged instrument about four feet in length, between the prongs of which there are several upturned spikes. On this string of tools being allowed to fall heavily on the coil of cable it seldom fails to secure a firm grip, but if the tools have become imbedded in the debris at the bottom of the bore hole, the trip link will come into operation allowing the grab to be jerked upwards, thus tearing off fragments of the broken rope until the head of the lost tool or tools is felt.

Lost tools.

When a tool is lost through breakage of the cable at the tool or when the cable has been jerked off as above, then the tool is recovered by feeling with a worm screw or cleat the worm of the former engaging in the swivel hook of the tool, or the L-shaped portion of the cleat can be hooked round the neck, under the swelled head of the rod socket.

Unscrewed and broken rods.

Rods becoming unscrewed can be recovered by lowering a bell box over the head of the unscrewed rod. The bell box consists of a short length of tapered tube,.the wide mouth of which is an easy fit in the bore tube, the upper end being provided with a semi-circular flap valve. On lowering this tool over the rod, the valve is pressed up and on withdrawing the tool, the valve presses down and jambs under the neck of the rod.

In the case of broken rods the bell box is replaced by a bell screw which is similar in shape to the bell box, only the flap valve is replaced by a hard steel die; this tool is lowered by rods or tubes from the surface and on these being turned a screw is cut on the broken rod end and the lost tools recovered.

Broken tools.

Considerable trouble can be caused by a boring tool breaking when firmly stuck in a hard soil or rock, as there is no head or neck which can be gripped or screwed and sometimes, if the broken portion is not already stuck in the soil, it may become wedged owing to the searching operation, or it may be inclined at an angle under the cutting shoe of the bore tube.

The position of the broken piece can be found by lowering an impression block : this consists of two forms according to requirements, either a circular disc of wood attached centrally to the boring rods, the lower surface of which is studded with nails projecting half an inch from the wood surface and plastered over with clay puddle, or it may consist of a long cylindrical or slightly tapering piece of wood, the surface of which is similarly coated with plastic clay or other substance. The position of the broken piece having been found, it may be forced into a more suitable position for removal by twisting the cleat hook behind it ; if firmly wedged the piece may be loosened by boring around it with smaller sized tools or by the water jet. When loosened the tool may be picked up by the grab tongs, one form of which is shown on Fig. 20. Sometimes it is necessary to lower a drill at the end of the boring rod and drill and tap the broken piece, the drill and tap being kept in the correct position by spring guides attached to the boring rod and pressing on the boring tube. If the position of the broken tool is favourable and the subsoil hard, it may be pulverised and driven to one side clear of the bore tube with a steel bit at the end of heavy sinking rods. For extreme cases, in deep borings where it is less expensive to remove a broken and firmly fixed tool than to abandon the boring, the tool may be cemented in with portland cement, and when set hard the whole plug and the tool may be drilled through with a calyx or diamond drill.

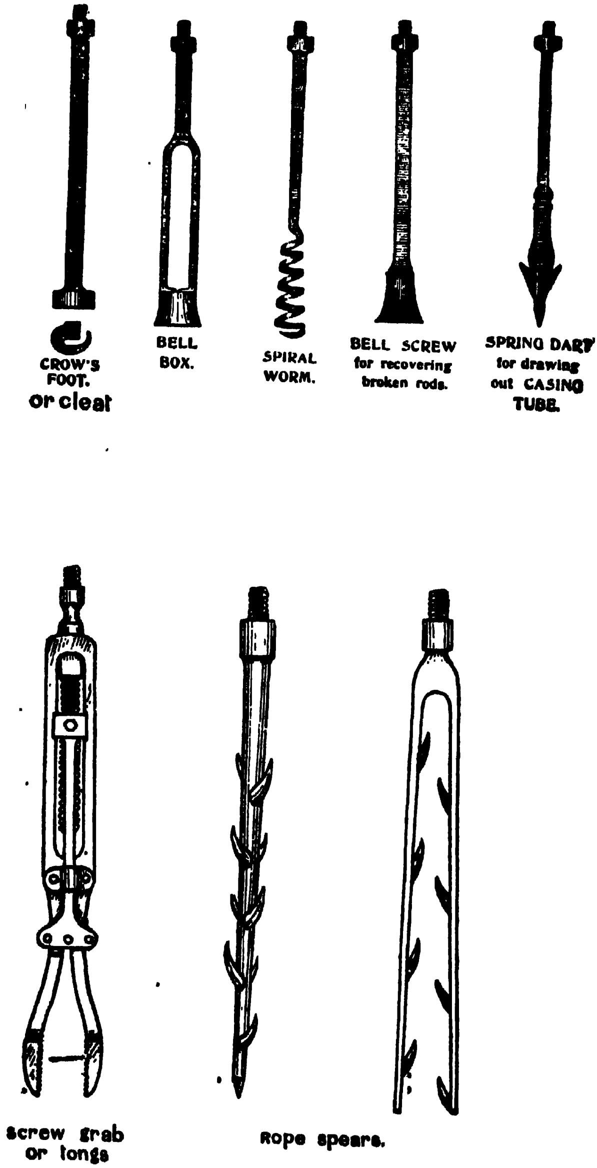

CROW'S FOOT. or cleat
BELL BOX.
SPIRAL WORM.
BELL SCREW for recovering broken rods.
SPRING DART for drawing out CASING TUBE.
screw grab or tongs
Rope spears.

Fig. 20.

DEPTH OF BORING.

For tube wells which are to be sunk from ground surface the minimum depth of boring should be equal to the length of the convoluted tube well, plus 20 feet, plus the depth from ground surface to dry weather spring level. When the convoluted tube is to be sunk in an existing well, the top of the convoluted tube should generally be not less than 10 feet below the bottom or floor of the well. These depths assume that a good water bearing stratum of at least the required depth exists ; it may frequently be found that by continuing the boring to a greater depth a much coarser and more highly porous sand exists. In such cases it is advisable to sink the convoluted tube deeper and thereby obtain the required discharge under a less head than would otherwise be the case. Again, the water bearing stratum may not be continuous but may be intersected by strata of clay or other impervious material ; for example, in the writer's experience of one district a good water bearing sand stratum was intersected at a depth of 30 feet below spring level by a stratum of clay 10 feet thick. It was desired to sink a 5-inch convoluted tube well for a discharge of 15,000 gallons per hour. The length of this size of tube well is 54 feet. The boring was continued to a depth of 74 feet below spring level and 34 feet of convoluted tube well inserted, then a 10 feet length of plain pipe and then the remaining 20 feet of convoluted tube ; thus the clay stratum was passed by a plain pipe. There is sometimes only a limited depth of water bearing stratum and in such cases the full length of convoluted tube cannot be made use of ; in one instance the writer was asked to provide a supply of 40,000 gallons per hour and the intention was to sink two standard 7-inch tubes, each 74 feet long. On boring operations being commenced it was discovered

that the water bearing stratum only extended to a depth of 50 feet below spring level, so the 7-inch convoluted tube wells were halved and the four halves used as separate tube wells; but instead of attaching a 7-inch plain tube to the upper end of the convoluted tube, a reducing socket was fixed and a 5-inch plain pipe attached, the object of this reduction being to ensure all sand which came into the tube well during the first few days of working, being held in suspension and thereby carried out of the tube: in other words, the 5-inch pipe provided a higher velocity than would have been the case with the 7-inch pipe.

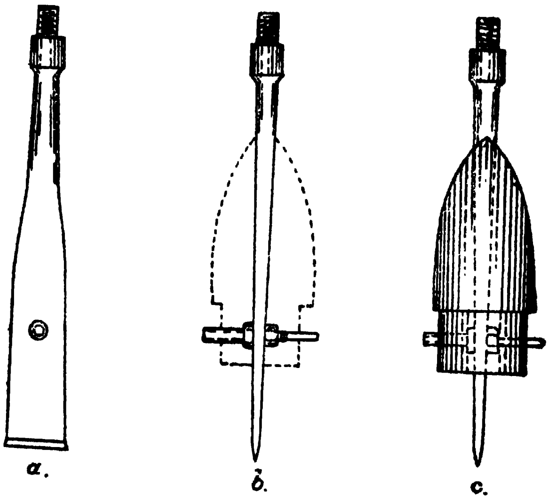
SINKING CONVOLUTED TUBE WELLS.

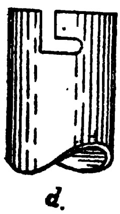
HAVING settled on the size of tube well required and the boring completed, the next operation is to sink the tube well. Convoluted tube wells are sent out in lengths of from 7 to 10 feet according to the diameter, and it will be observed that one length is provided at one end with a cap or blind end, this is the first length to be inserted in the bore. One of the iron clips supplied with the tube wells is clamped to the upper end of this first length, *i.e.*, the end which is open, and the clamp should be fitted just under the socket so that the socket acts as a shoulder and prevents the tube slipping through the clamp, should the latter not have been securely screwed up. The rope passing over the pulley of the tripod is provided with a swivel hook and to this hook a short double chain sling should be suspended; the hooks of the chain sling are slipped under the projecting lugs of the clip and the length of tube well raised and suspended over the bore tube and then gently lowered in the bore tube until the lugs of the clip rest on the mouth of the bore tube. A second clip is now fixed under the socket of the second length of tube and this length raised and its lower or spigot end slipped into

the socket of the first length; a mark will be found on the socket of the first length and a corresponding mark on the spigot of the second length must be brought opposite this mark, the stud holes of the socket and spigot will then correspond and when the studs are screwed in, the axes of the two lengths will be in one straight line. The clamp is now removed from under the socket of the first length and the two lengths lowered until the lugs of the clamp fixed under the socket of the second length rest on the mouth of the bore tube; the operation is repeated until all the lengths have been coupled up and the clip lugs of the last length of convoluted tube are resting on the mouth of the bore tube; the first length of plain pipe is now coupled to the upper end of the convoluted tube by a similar type of stud joint as employed in the convoluted tube, the remaining lengths of plain pipe may be jointed by the ordinary screwed socket joints with which the plain pipes are usually provided. If pumping is to be done from ground surface, this plain pipe will be continued up to ground surface and temporarily closed with a wood plug; but if the tube well is to be used to augment the supply in an existing well, or if a sump is to be used for pumping purposes, then the upper end of the plain pipe will be say, 12 feet below dry weather spring level. In this latter case the method of lowering the tube well is as follows :—

The convoluted tube and the plain pipe attached is lowered as above and the clip secured under the socket of the last plain pipe supports the whole tube well on the mouth of the bore tube. Two L-shaped slots are cut in the socket of this plain pipe and into these slots a lifting tool is fixed. The lifting tool (see Fig. 21) consists of a short length of flat bar iron, one end of which is screwed to fit the ordinary boring rods, a hole is drilled in the bar and fitted with a piece of round bar

DETAILS OF LIFTING TOOL





(*a*) Boring chisel from which lifting tool is made.
(*b*) Side elevation of chisel showing lifting bar fixed.
(*c*) Showing wood shield built round tool.
(*d*) Upper end of plain pipe with slots cut.

Fig. 211

iron provided with a shoulder and lock nut to secure it centrally on the flat bar, the ends of this round bar are slipped into the vertical portion of the L slots on the socket, the bar is given a part turn to the left, thus engaging the horizontal position of the L slots. In order to provide a temporary plug for the tube well, this tool should be built round with wood as shewn in B. & C. Fig. 21. The tube well is now lowered in exactly the same manner as when the plain pipe comes to ground surface, only lengths of boring rod are used in place of the plain pipe and the tube lowered until it rests on the bottom of the bore hole. The tube well is now ready for shrouding.

Shrouding the tube well.

The material used for shrouding the tube well is a good coarse clean sand, carefully screened to the size which will pass through a screen having 10 meshes to the lineal inch and will be retained on a screen having 40 meshes to the lineal inch. The quantity of this sand which is required to fill one foot of the annular space between the convoluted tube and the bore tube, should be carefully calculated and the calculation verified by an actual test on a short length of boring pipe with a piece of convoluted tube, or other tube of exactly the same dimensions, placed inside the bore tube. A tin measure of $\frac{1}{8}$th cubic foot capacity is a convenient size to use for filling in this sand: the measure should be filled each time and sufficient sand poured into the space between the convoluted tube and the bore tube to fill a depth of two feet, the bore tube should then be withdrawn one foot only, and again sand poured in to fill a depth of one foot only, the bore tube withdrawn one foot and a further depth of one foot of sand poured in, and so on, for the entire length of the convoluted tube. By this method of filling the sand is always one foot higher than the bottom of the bore tube, thus en-

suring a continuous jacket or shroud of the coarse sand round the tube well. If the sand is filled in for a greater depth than one foot at a time without drawing the bore tube, the sand is liable to bind on the convoluted tube when drawing the bore tube and the straining material may be damaged, or if a considerable depth of sand is filled, then the convoluted tube may be sand-bound to such an extent that it will be raised with the bore tube; it is, therefore, expedient to keep the sand never more than two feet or less than one foot in advance of the bottom of the bore tube. Although shrouding is not absolutely necessary in subsoils of which the particles are larger than will pass through a screen of sixty to eighty meshes to the lineal inch, still it forms a considerable protection against packing on the outside of the straining material and as it ensures a high porosity subsoil in contact with the straining material from the start it is quite worth the little trouble and cost involved.

Drawing the bore tube.

The bore tube is withdrawn while the shrouding described above is being applied, the method of withdrawal being as follows :—The wood clamp which is used for carrying the load in sinking (see Fig. 15) is secured to the boring tube a short distance above the timber platform fixed at ground level; two screw or hydraulic jacks are placed on the platform, one on each side of and close to the bore tube, the upper lifting plates of the jack bearing on the underside of the wood clamp, as the jacks are screwed or pumped up the bore tube is withdrawn, the wood clamp being moved down from time to time to suit the range of the lifting jacks When the bore tube has been raised so that the first joint is from two to three feet above the timber platform, the clamp should be moved down to the timber platform and held with a crowbar to prevent the bore tube from turning when the upper length is being unscrewed.

To unscrew the upper length of bore tube a long crowbar placed against and at right angles to the bore tube is wrapped twice round with a length of light chain, which is then wrapped several times round the bore tube; this crowbar acts as a powerful lever operated by several workmen holding the lever and marching round the bore tube in an anti-clockwise direction; the first movement of the crowbar serves to tighten the chain on the bore tube, friction then being sufficient to hold the lever as part of the bore tube which is unscrewed as the lever is turned round. An iron clamp should be secured to the upper end of the length of bore tube which is to be unscrewed and this clamp hooked to the chain sling hanging from the swivel hook of the lifting tackle on the tripod, the lifting tackle taking the weight of the length of bore tube as soon as it is unscrewed.

Bore tubes of 12 and 15 inches diameter can be easily withdrawn by the above method from borings up to 200 feet in depth, at the rate of 70 feet per working day.

Having completed the withdrawal of the bore tube the tube well is now ready for use, unless the tube is sunk in a well in which the water level is to be reduced below that level, which would exceed the critical velocity of the subsoil forming the well floor; or if the tube well is sunk in a small chamber or well to be used as a pump sump. In such cases the floors of the wells or chambers should be sealed with cement concrete. A good substantial seal should be put in, say, from two to three feet in thickness, and the writer has proved that a four to one cement concrete is most suitable for this purpose. The concrete is composed of one part best portland cement, two and three-quarter parts stone broken to pass through a one and a half inch ring and one and a quarter parts clean *sharp* river or pit sand, all by measure; if one cubic foot is taken as the unit of measurement, then the

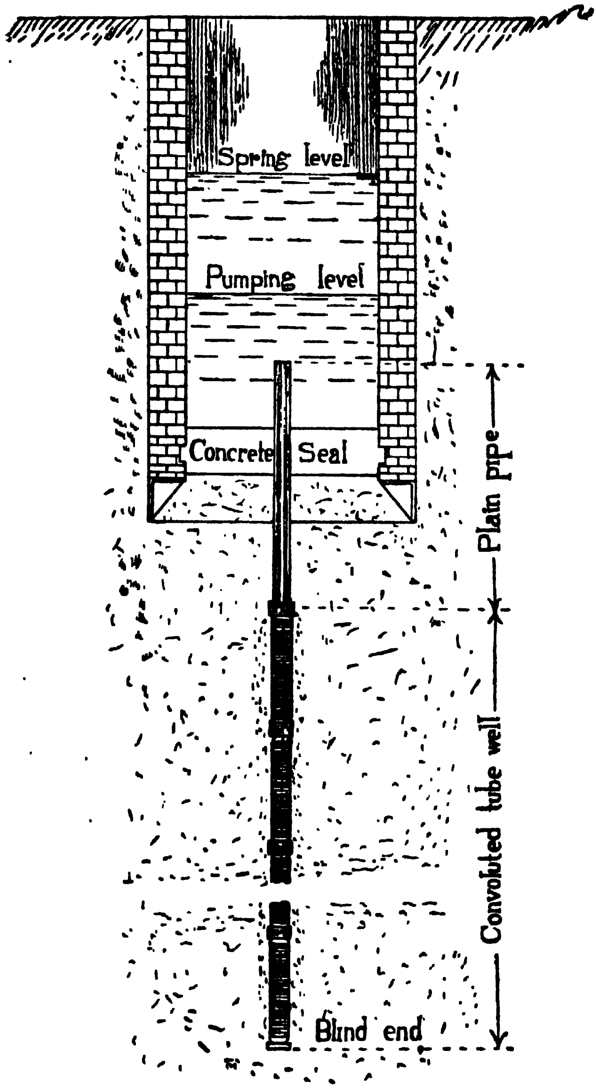


Fig. 22.—Tube well sunk in existing well (concrete seal may be omitted if critical velocity of well is not to be exceeded).

total of five cubic feet according to the above proportions will be found quite sufficient to mix at one batch. The ingredients should be thoroughly mixed in the dry state and again mixed with the addition of just sufficient water to damp all particles ; the mixture is now ready for loading into the well or pump sump, and this is conveniently done from an ordinary galvanised iron bucket. A few holes are made in the bottom of the bucket and a rope secured to one of the holes, the other end of the rope is secured to the handle ; concrete is put in the bucket and lowered by the rope attached to the handle until the bucket rests on the floor of the well, then the rope attached to the bottom of the bucket is used to raise the bucket, thus upsetting and emptying the bucket at the bottom of the well, the additional holes in the bottom of the bucket allowing water to pass in and expedite the emptying of the bucket ; this method prevents the cement from being washed out from the other ingredients and gives a substantial water-tight floor ; when the well is being specially sunk as a sump for a tube well, the masonry walls for a foot or two above the curb should be built corbelled out and in, to act as a bond for the reception of the concrete and obviate the straight joint between the masonry and concrete.

PUMPING FROM TUBE WELLS.

Bullock wheels.

WITH the smallest size of convoluted tube well capable of yielding one quarter cusec, or over 5,000 gallons per hour, the ordinary Persian wheel is most often employed ; the reason being that this size of tube well is frequently used for increasing the water supply of existing wells for irrigation purposes, in which a Persian wheel is already working. Few of the old wood Persian wheels lift more than 2,000 gallons per hour and the wheels are frequently duplicated when a small tube well has been

Fig. 23.—Cawnpore bullock power patent chain pumps.

installed, or bullock power metal Persian wheels or chain pumps substituted for the wood Persian wheels. When the old-fashioned wood wheels are used it is advisable to fix a globe-shaped wire cage over the mouth of the tube well to prevent broken earthenware vessels dropping from the Persian wheel into the tube. Fig. 23 shows a general arrangement of metal gearing for bullock power and chain pump in use in tube well augmented wells.

Power pumps.

For irrigation purposes or public water supply from the larger sizes of convoluted tube wells, power pumps will be required and local conditions must decide the type of pump and whether it is to be driven by steam, electricity or oil, etc.

When water level is within 10 or 12 feet of ground surface, then the pump may be placed on ground surface and either connected direct to the tube well or the tube well may be sunk in a small pump sump of three or four feet diameter and the suction pipe from the pump carried down into the sump. Fig. 24 illustrates direct pumping from tube. The disadvantage in direct pumping from the tube is that on reduction of pressure due to pumping the air held in solution in the water is released and has to pass through the pump, thus reducing the efficiency of the pump. The simplest method of avoiding this in situations where subsoil water is near ground surface, is to pump from a sump and in cases where water is some considerable distance below ground level, the suction pipe of the pump should be carried inside the plain pipe of the tube well, thus providing an annular space between the two pipes which permits of the escape of a considerable quantity of air.

Pumping by the air lift system.

Compressed air as a means of lifting water from tube wells is in favourable circumstances a simple method of operating either a battery of several tube wells from one compressor plant, or it may with equal economy

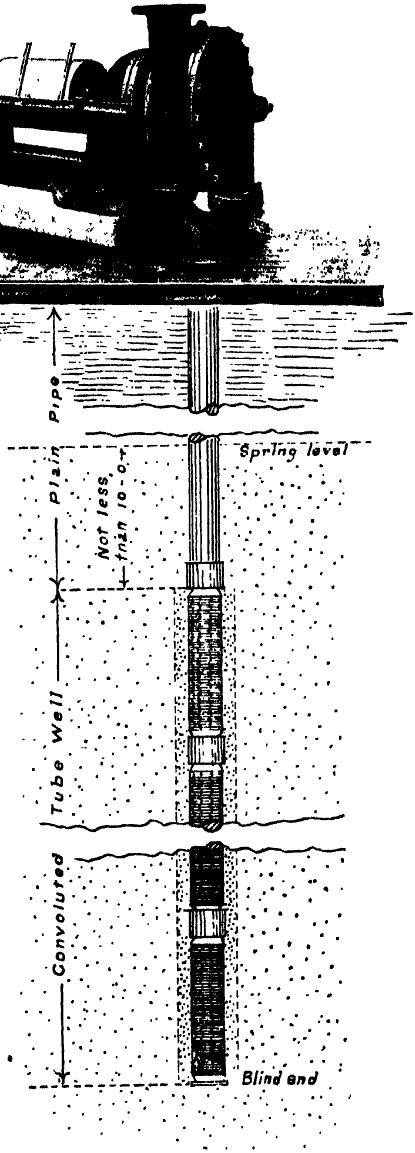


Fig. 24.—Direct pumping from tube well by centrifugal pump.

be employed to pump from only one tube well. For a large water supply requiring several tube wells, the most economical arrangement is to sink the tube wells equidistant on the circumference of a circle at the centre of which the compressors are situated; the water delivery pipes from each tube well radiating to collection or storage tanks situated over the compressors. This system allows an exceptionally large scope for extension, as additional wells can be added as required on a concentric larger circle.

In order to obtain as high an efficiency by the air lift system as by ordinary pumps, the amount of submergence of the air inlet should be carefully fixed; when the lift is small the submergence may be as much as 2½ times the lift, but on high lifts it is not advisable to have a submergence much more than equal to the lift. For example, where water level is 30 feet below the point of discharge, the submergence over the air nozzle should be about 75 feet; when water level is 300 feet below the point of discharge, a submergence of 300 feet would be ample. In dealing with high lifts and consequently high air pressures, there is considerable falling off in efficiency if the submergence is too great.

The quantity of air required to pump any given quantity of water depends not only on the submergence, but also on the height to which the water is to be lifted. When the lift is 100 feet and the air inlet submerged 200 feet, then 0·62 cubic feet of free air is required per gallon of water. If the air inlet is submerged 200 feet and the lift increased to 200 feet, then 1·25 cubic feet of air is required to lift each gallon of water.

The air pressure required depends on the amount of submergence and lift. With a lift of 200 feet and submergence of 200 feet the working pressure would be between 85 and 90 lbs. per square inch representing

the water weight over the nozzle of air inlet. This working pressure has to be considerably exceeded in order to start pumping by overcoming friction in the rising main, and inertia of the long column of water.

Tube wells which are to be worked by the air lift system require to be made deeper than when other types of pumps are employed; this is in order to allow the air inlet the proper amount of submergence, the air inlet nozzle should be placed in the plain pipe and close to but not within, the convoluted tube pipes. Fig. 26 shows the correct position of the air inlet and general arrangement of the plant when in use with convoluted

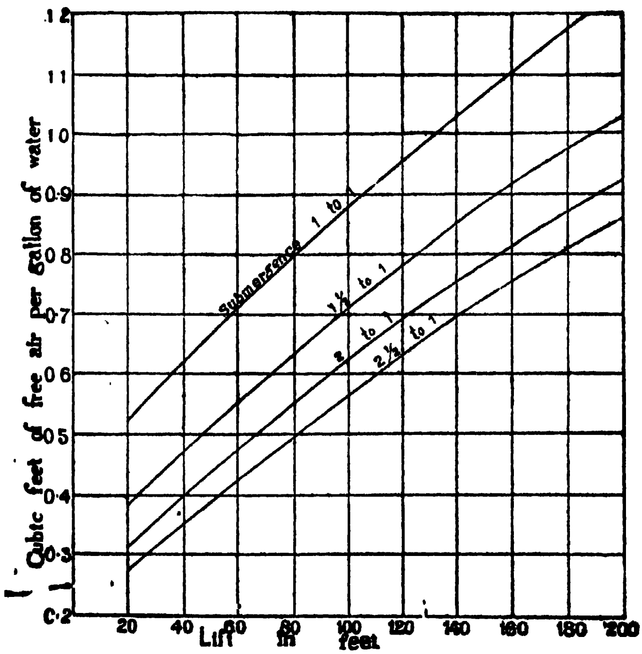


Fig. 25.—Diagram showing quantity of free air required per gallon of water with varying submergence of air nozzle.

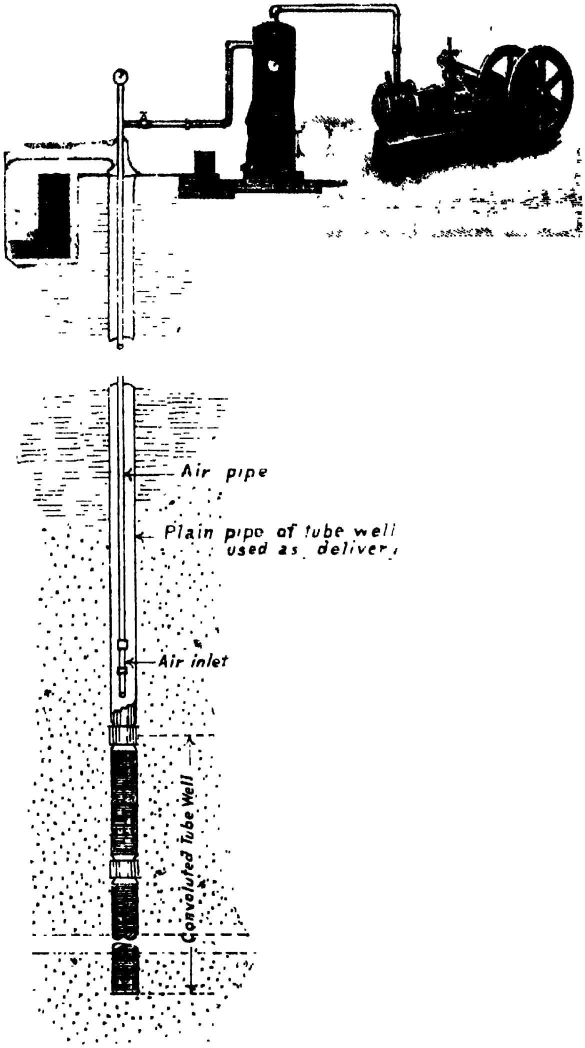


Fig. 26.—General arrangement of Worthington Air Lift system, for raising water from deep tube wells.

Note.—It is sometimes advantageous to keep the air pipe outside the delivery pipe, thus avoiding the obstruction and friction caused by air pipe.

tube wells. The air pipe may be led down the outside of the rising main or discharge pipe and this arrangement is preferable to carrying the air pipe inside the rising main and thereby increasing friction owing to additional surface and the couplings of the air pipe. In many cases, however, this friction may be neglected and considerable saving effected by using the plain pipe of the tube well as the rising main and inserting the air tube therein as shown in illustration.

The beauty of the air lift system is its simplicity: there are no parts whatever in the tube well which are likely to become worn or give any trouble, no matter what the water depth may be; all the plant is at ground surface and easily accessible.

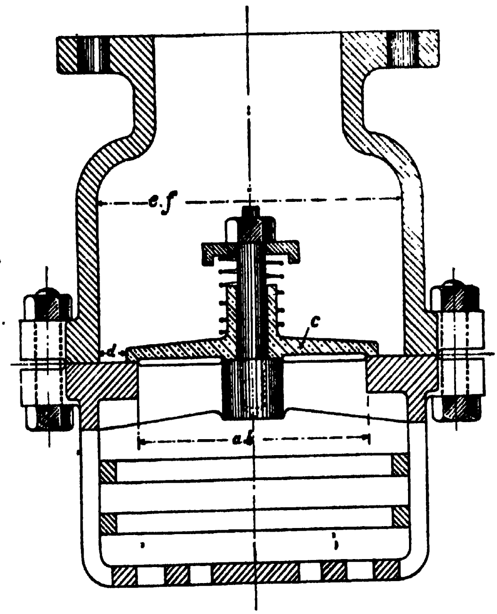


Fig. 27.

SUCTION VALVES.

THERE are few cases in which a foot valve is not a necessity in tube well pumping schemes, and if the ordinary standard types of mushroom or hinged flap valves are employed, a considerable amount of expensive masonry or iron work has to be used in the work on account of the large size of these valves.

For example, assume that a tube well has been sunk for a discharge of 1½ cusecs, the plain pipe of the tube well being ten inches in diameter; for this discharge a convenient size of pump suction pipe would be eight inches diameter. Now an ordinary mushroom valve, in order to have a free waterway area, requires to have the waterway opening *ab* (Fig. 27) equal to the diameter of the suction pipe, plus the area taken up by the web which supports the valve spindle. In the case under consideration the diameter would be 8·5 inches, while in order to form a water-tight joint between the valve and its seating, the valve *c*, must overlap the opening to a certain extent, in this case 0·5 inch, making the diameter of the valve 9·5 inches. Further, for the free passage of water past the valve, the annular space *d* requires to have an area equal to the area of the suction pipe, thus making the total internal diameter *e f* of the casting 12·5 inches for an eight inch valve, and to this has to be added the thickness of metal in the casting and bolt ways, making the overall dimensions 15·75 inches. Whatever the size of the valve used, the proportions are approximately the same, *i.e.*, the overall dimension of the valve is roughly twice the diameter of the suction pipe. Obviously an eight inch valve of this type cannot be inserted in the ten inch pipe of the tube well, and to enlarge this pipe sufficiently to take the valve, or to use a casing pipe large enough to take the valve, renders the work from a financial point of view impracticable.

The practice hitherto has been to fix this ordinary type of valve near or below the natural water level, and to extend the suction pipe below the valve. This entails the use of a chamber sunk low enough to take the valve, and adds considerably to the cost of the work. If the valve be placed any distance above water level, considerable difficulty is experienced in priming the suction pipe, and waste of time in starting the plant results.

NEW PATTERN FOOT VALVE.

In order to avoid this unnecessary work and to reduce the initial cost in tube well installations, a form

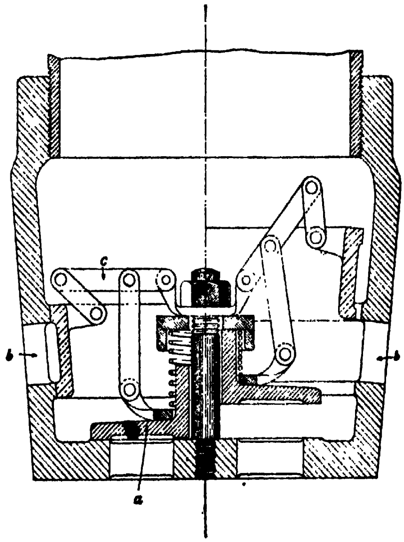


Fig. 28.

of foot valve has recently been manufactured, which, while having the full waterway area of the suction pipe, has an overall dimension less than two inches in excess of it, and therefore can be used at the bottom of the suction pipe in the manner usual in pumping plants, and can be inserted in the plain pipe of the tube well. Fig. 28

shows the general arrangement of this valve, which, it will be observed, is of the sleeve type, the casting being of conical section, carrying an ordinary mushroom valve *a* of small area on the truncated portion of the cone while the wall of the cone is perforated with rectangular openings *b*, the area of which, combined with the area of the mushroom valve opening, equals the area of the suction pipe. These openings are covered by an internal sleeve of gunmetal, and this is connected by a loose lever trident *c* to the mushroom valve. The lift of this valve is such, that the annular opening under its edge, when lifted, is equal in area to the waterway area of the valve and the amount of lift of the sleeve, in order to uncover the openings *b*, is roughly three times the lift of the mushroom valve, while the lever connection between this valve and the sleeve is so proportioned as to maintain the correct ratio of lift. The object of having the sleeve and its seat of a conical section is to ensure a water-tight fit after wear has taken place, the amount of taper provided being sufficient to prevent locking or jambing of the sleeve in its seat.

The action of the valve is as follows :—On the pump being started and the air pressure in the suction pipe reduced, the mushroom or pilot valve is forced up by the external water pressure, and in lifting, raises the sleeve, thus uncovering the full waterway area required in the valve.

Foot valves of this description cost nearly fifty per cent. more than the standard foot valve, but the additional cost is saved many times over in the reduction in masonry and iron work used in erecting the plant. In districts where the subsoil water level is at such a depth as to render vertical spindle, centrifugal, or reciprocating pumps economical, then drowned pumps may not require foot valves, while a reciprocating pump inlet can be made on the sleeve valve principle.

A further advantage in the use of this valve is due to the greater quantity of the water being drawn through the side of the valve instead of from the bottom mushroom valve. This arrangement allows the air in solution, as it is released from the subsoil and rises rapidly through the water, to continue rising vertically in the water column between the suction pipe, and the plain pipe or sump. When water is drawn into the suction pipe from a horizontal mouth, it carries into the pipe a larger percentage of air than when the air has a free field of vertical rise to the atmosphere, and water is withdrawn at right angles to that field.

It has been asserted that the amount of air pumped with the water depended on the position of the pump; needless to say, this view is entirely erroneous, for if no outlet from the tube well is provided for the escape of the air, it must pass through the pump, whatever its position happens to be.

Various types of pumping plant.

It is impossible to give particulars of all the forms of pumps which may be successfully employed for lifting water from tube wells, as local conditions and requirements must decide the type and power best suited for individual cases. The horizontal reciprocating pump is largely used for public water supplies in India and this form is well suited for all situations where the spring level is fairly near ground level; the power most generally in use for driving these pumps is steam and the pump barrel is arranged in tandem with the steam cylinder; one piston rod carries the piston at one end and pump plunger at the other, thereby allowing of an extremely neat and compact arrangement. A pump of this type may be fixed at ground level and the plain pipe of the tube well connected direct to the suction pipe of the pump, or in cases where water level is beyond the economical suction reach of the pump, the pump may be placed

on cross girders in a pump sump close to water level, while the steam boilers are placed at ground level. When a battery of tube wells is required to yield the necessary supply, they may be arranged as in the air lift system with a separate suction pipe radiating to one main suction chamber of the pump, or they may be arranged in a straight line having the pumping plant midway on the line and a main suction pipe lying parallel and close to the tube wells with a branch suction pipe to each well.

Although the pumps may be connected direct to the plain portion of the tube well and a special form of suction or foot valve fitted to each tube well when sinking it, or the valve may be omitted and a starting injection used in its place ; the author prefers to sink each tube well in a small diameter pump sump. In cases when spring level is comparatively close to ground level this sump may be of masonry, an internal diameter of three feet being sufficient, the bottom of the sump should be twelve or fifteen feet below spring level according to subsoil and be sealed with a cement concrete plug, the plain pipe of the tube well passing two or three feet through the plug into the sump. This arrangement, although slightly more expensive than with a direct connection to the tube well, allows of a much less expensive form of foot valve being employed and of complete accessibility to the foot valve for repairs, etc. The tube well may be examined or washed out in a few minutes without the necessity of excavation or disconnecting any pipes.

For general water supplies and irrigation purposes where the spring level is comparatively close to ground level and thus allowing of any of the ordinary forms of pumps being employed, the author prefers to use centrifugal pumps in most cases, chiefly on account of their freedom from valves or parts liable to get out of order, general simplicity and small space occupied.

Fig. 29 represents a centrifugal pump direct coupled to a Reavell two-cylinder high speed paraffin engine, this form of pumping plant is extremely compact and strongly built and so free from vibration that it will work well when suspended from a crane or standing on any class of floor without being fixed thereto. A plant of this type, capable of pumping over 30,000 gallons of water per hour, can be placed on a platform in a sump of eight or nine feet in diameter and will allow ample space for the mechanic in charge to attend to it in every way.

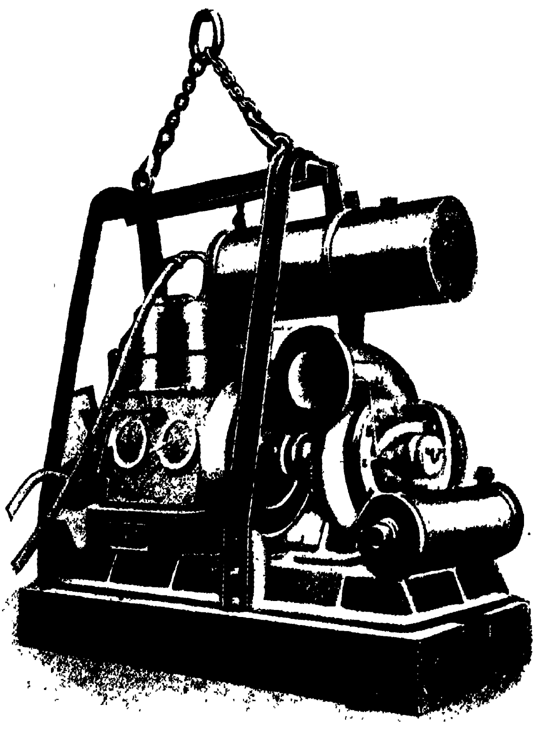


Fig. 29.—Reavell high speed engine direct coupled to centrifugal pump; arranged for slinging on cable.

In cases where an existing open well has been the only source of water supply of two or three thousand gallons per hour, the supply may be economically increased by sinking a tube well of the required discharge in the well, the floor of which is then sealed and a pumping plant of the above description mounted on a platform built a few feet above spring level. This direct coupled type of pumping plant is slightly more expensive than a centrifugal pump belt driven from the ordinary horizontal type of oil engine, but the small space it occupies frequently makes it a much less expensive plant to instal, on account of the absence of large engine houses which may require to be built considerably below ground level, in order to bring the belt driven pump within the economical suction reach of the water. These engines are fitted with Bosch magneto and are generally started on petrol for a few minutes until the required temperature is reached, but can also be arranged to start direct on kerosine oil, the required temperature being obtained by lamp heat applied for a few minutes as in many forms of the ordinary oil engine. The running cost of these engines compares favourably with that of the ordinary oil engine.

Fig. 31 represents a horizontal oil engine belt driving a centrifugal pump. Fig. 32 shows a typical case where the water level is fairly near ground surface, the pump having been stepped down a few feet to bring it close to water level. Fig. 33 shows the horizontal engine driving a horizontal centrifugal pump through a vertical shaft and twisted belt drive. This arrangement being suitable when water level in some considerable depth below ground surface, and yet not deep enough to warrant the use of a pump capable of working in the tube well itself.

Another popular form of pump suitable for these latter conditions is the double-acting vertical type of

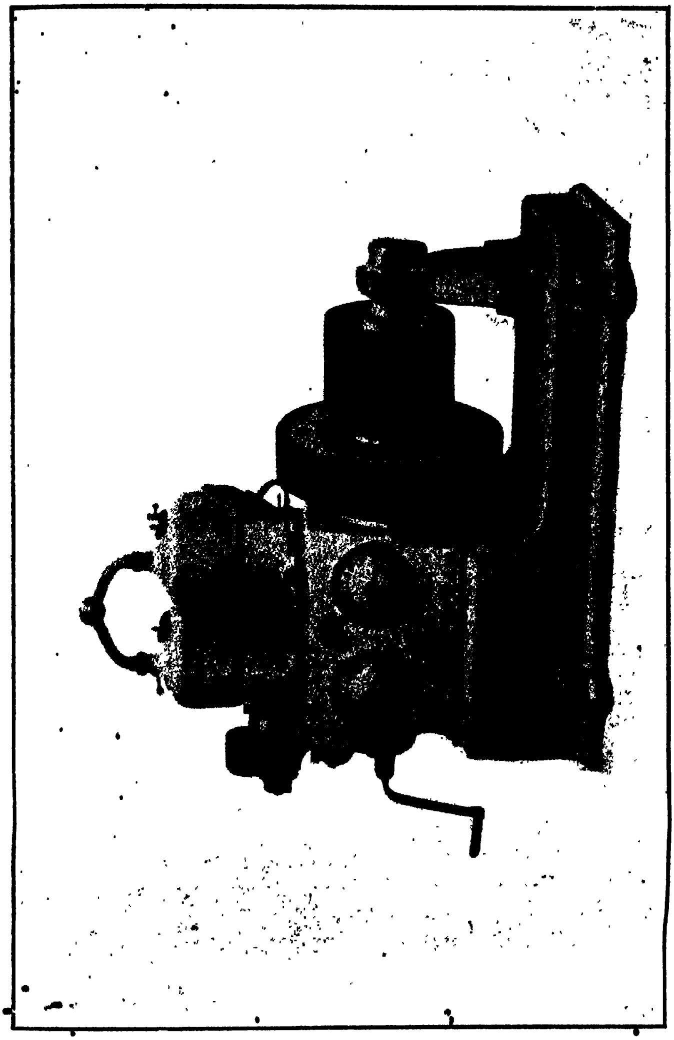


Fig. 30.—Reavell high speed engine arranged for belt drive.

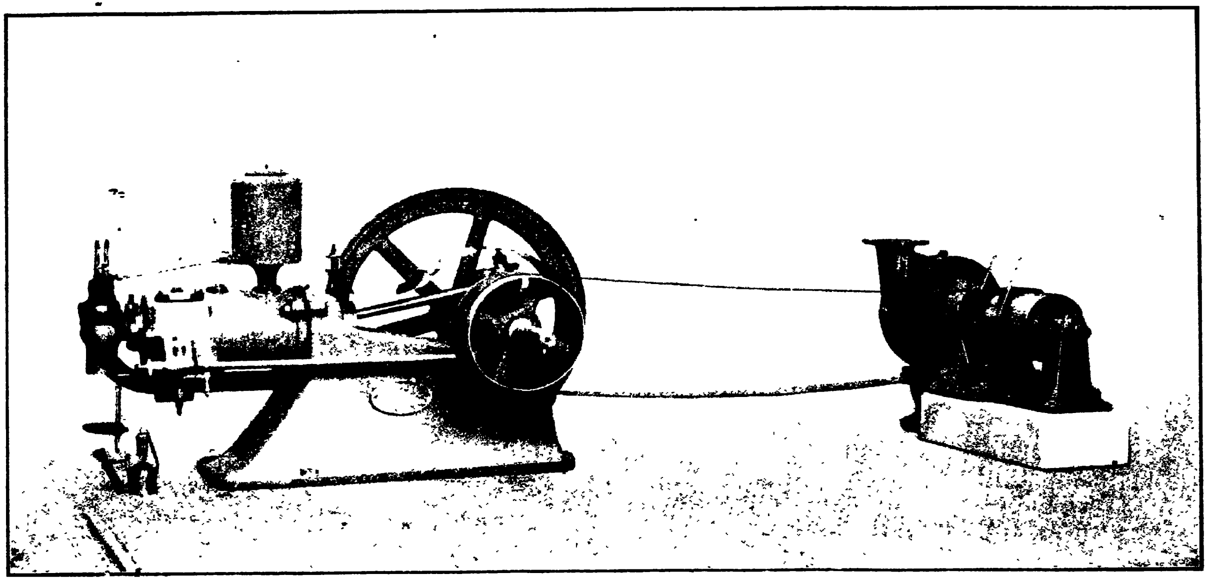
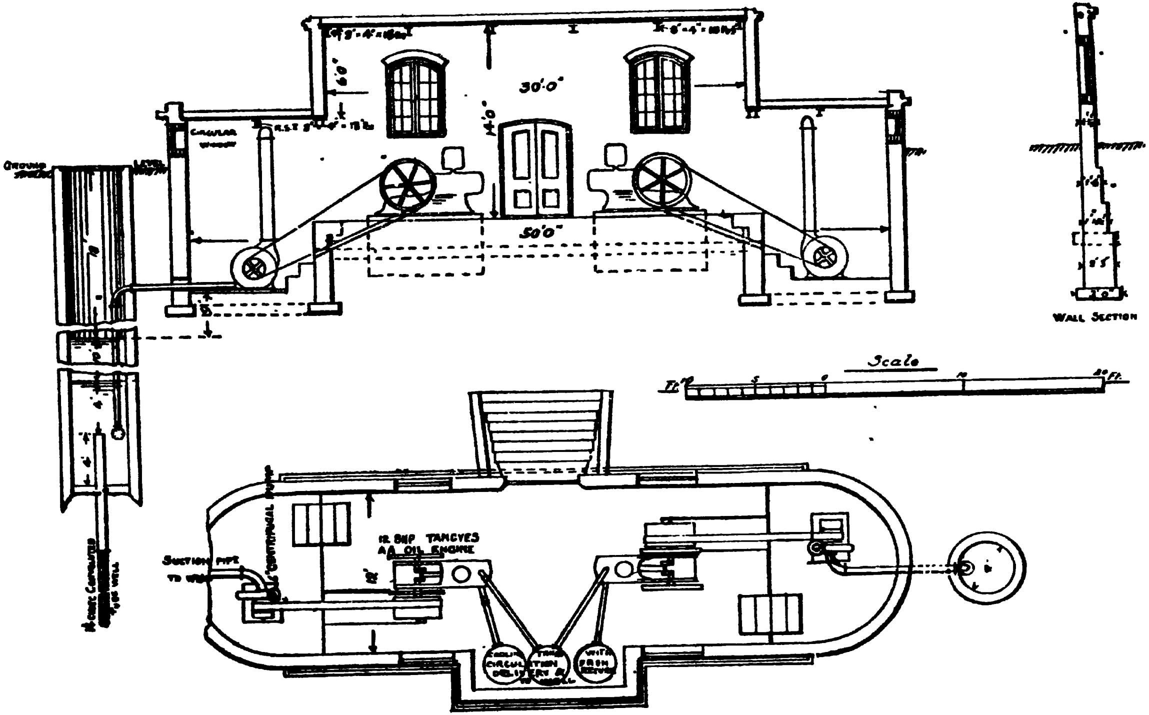


Fig. 31.—Tangyes' horizontal oil engine belt driving "Tangyro" pump.



ig. 32.—Pumping plant and tube wells in duplicate for supply of 28,000 gallons per hour.

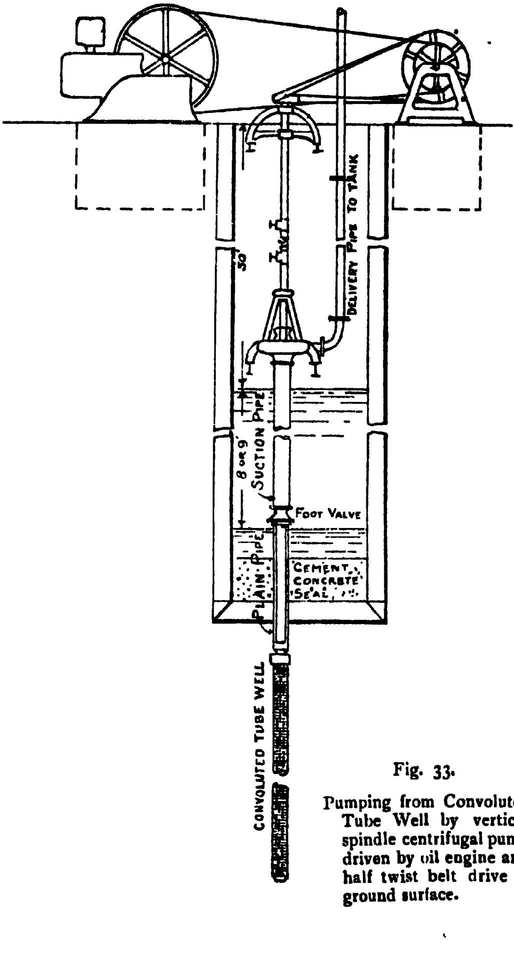


Fig. 33.

Pumping from Convoluted Tube Well by vertical spindle centrifugal pump driven by oil engine and half twist belt drive at ground surface.

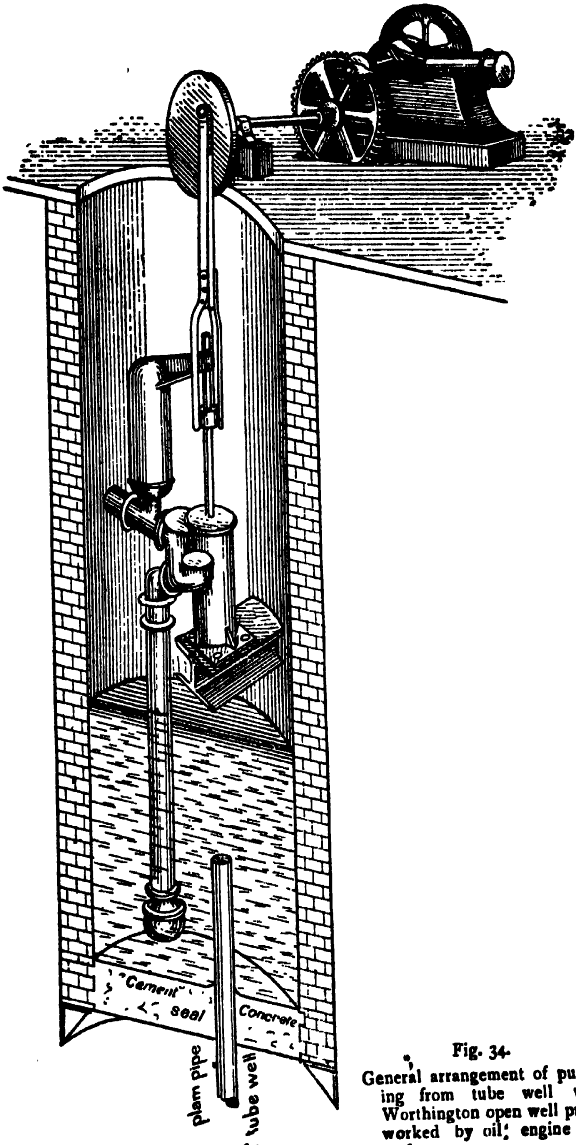


Fig. 34.
General arrangement of pumping from tube well with Worthington open well pump worked by oil engine at surface.

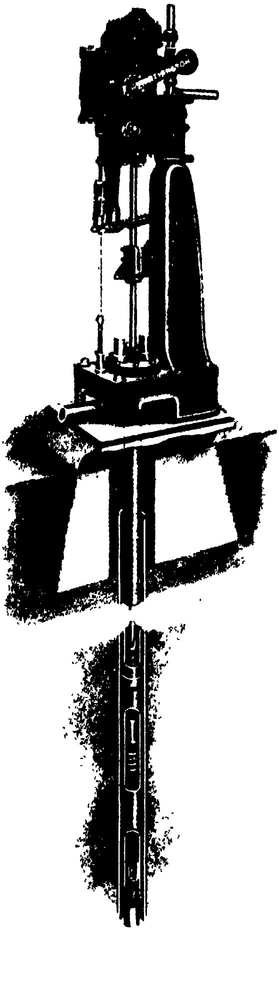


Fig. 35.—Worthington vertical steam engine and single artesian or deep well pump, working in plain pipe of tube well.

pump which is very compact and steady in its working. Fig. 34 shows a pump of this type bolted to a platform in the pump sump and driven by an oil engine at ground surface. Fig. 35 shows a somewhat similar type of pump driven by a vertical steam engine placed over the pump sump.

The power to be employed in driving pumps must be decided almost entirely by the locality in which the pump is to be worked. In many districts of India where the cost of coal is high on account of the distance from the coalfields and in districts in which there are no proper roads for the carriage of coal, oil engines can be run much more cheaply than steam engines. The author has installed a number of Tangyes' Oil Engines, some of which have been working for several years at a cost very much less than steam plant could possibly have run under similar conditions; these engines run on a low grade kerosine oil, the consumption of which is approximately three-quarters of a pint per brake horse-power per hour. Some of the other small sizes of well-known makes of oil engines run on crude oil and in the large sizes, engines of the Diesel type running on crude oil, generate power at an extremely low cost and occupy smaller space and require fewer attendants than steam plant of a corresponding power.

In districts where electricity at a favourable rate per unit is available, centrifugal pumps direct coupled to electro-motors, form a compact, silent, and highly efficient form of pumping plant, which can be run continuously with practically no attention. By this system a large number of tube wells may be pumped at a low cost and if the tube wells are arranged in the manner described for air lift pumping, the wiring is reduced to a minimum. The motor and pump must of course be within economical suction reach of reduced water level.

The following table shows approximate position of centrifugal pumps relative to spring level :—

Size of pump.	Capacity in gallons per minute up to—	Size of tube well.	Height of pump above spring level in feet.	Head of depression when pump is working ; according to subsoil.	Recommended maximum total suction in feet.
Inches		Inches			Feet.
3	140	3½	8 to 11	4 to 7	15
4	250	5	7 to 10	6 to 9	16
5	400	7	7 to 10	7 to 10	17
6	600	7	5 to 9	8 to 12	17
7	800	9	5 to 9	9 to 13	18

Tube well pumps.

WHEN spring level is at such a depth that any of the methods already described for bringing the pump within its suction reach are impracticable on account of cost, etc., or when local conditions preclude the economical use of the air lift system, then it is necessary to employ a tube well pump. These pumps may be worked at any depth from 20 feet to 2,000 feet if desired, and in order to allow room for them the plain pipe from the tube well must be of large diameter: for example, a pump to deliver 34,000 gallons per hour would require to have a plain tube of 15 inches internal diameter attached to a 9-inch convoluted tube well which is capable of discharging 45,000 gallons per hour; and a pump delivering 10,000 gallons per hour would require to have a plain pipe of 9 inches internal diameter attached to a 5-inch convoluted tube well.

There are two methods by which the large plain tube can be fixed, the simplest method is to sink the original boring tube of a size sufficiently large to allow the large plain pipe to slip freely through it. The plain pipe is secured to the convoluted tube well with a reducing piece of the required size and lowered into the

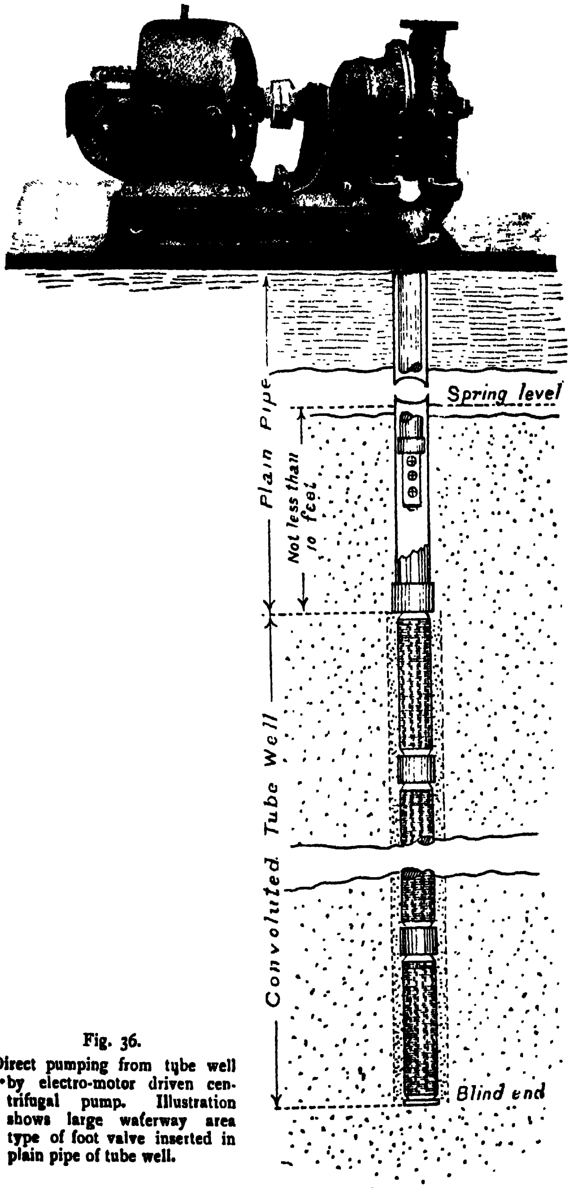


Fig. 36.

Direct pumping from tube well by electro-motor driven centrifugal pump. Illustration shows large waterway area type of foot valve inserted in plain pipe of tube well.

bore tube as previously described, sufficient plain pipe being added to reach to ground surface and then the original bore tube is withdrawn. Another method is to sink the original bore tube of a size sufficiently large to allow the pump to pass freely into it, for example, in the case of a pump for 10,000 gallons per hour, a bore tube of at least 9 inches diameter is sunk to the required depth and into this the 5 inches diameter convoluted tube well with say ten feet of 5-inch plain pipe attached is lowered. The bore tube is now withdrawn sufficiently to bring its lower edge level with the top of the convoluted tube: thus the bore tube overlaps the plain pipe attached to the tube well; the space between the bore tube and plain pipe is then rendered water-tight with a cement plug and the bore tube is ready to receive the pump, etc.

The pump barrels with the rising main are now lowered into the tube to a depth of ten to 15 feet below spring level according to circumstances, the plunger with the plunger tubes or rods attached is next lowered into the pump barrel and the pump is ready for work. Pumps of this type are known as the "Ashley" pump made by Glenfield and Kennedy, Ltd., and the double-acting artesian well pumps are made by the Worthington Pump Co., Ltd. Both pumps are double-acting thereby equalizing the load and, as all valves are attached to the bucket or plunger, they can be simply and expeditiously withdrawn when necessary, by raising the rods only. The "Ashley" pump is provided with an extremely ingenious arrangement for automatically balancing a varying load caused by a large rise or fall of water level in the bore tube.

Tube well pumps may be connected to any form of well head and driven in the ordinary way by steam, oil, electric power, etc. Fig. 38 shows a favourite type of steam drive for these pumps; the cylinder is arranged

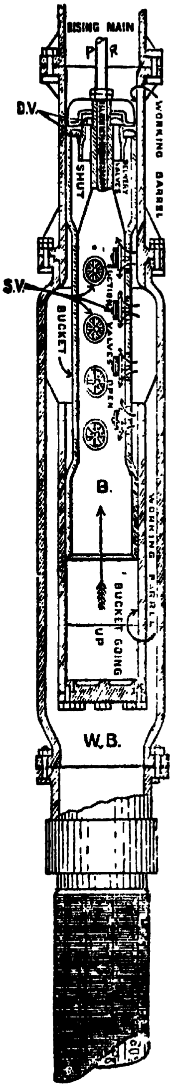


Fig. 37.
(P. R.)—Pump rod.
(D. V.)—Delivery valve.
(S. V.)—Suction valve.
(W. B.)—Working barrel.
(C.)—Tube well.

DETAILS OF
ASHLEY'S PUMP.

in such a way that it can be swung round, leaving the bore tube clear for withdrawal of the plunger for repairs, etc. Fig. 37 illustrates the double-acting form of 'Ashley' pump, and it shows diagrammatically the general arrangement of pump, tube well, etc.

In cases where a larger supply of water is required than can be obtained from one tube well, two tube wells may be sunk at a distance of ten or 12 feet centres and worked by deep well pumps coupled to the one engine by bell cranks and connecting rods.

EXCLUDING SURFACE WATER.

In many districts the surface water is brackish or otherwise unwholesome, while by continuing the boring to a greater depth a supply of good potable water may be obtained. When the brackish water is separated from the good water by an impermeable stratum of clay or rock, etc., it is a simple matter to prevent the surface water from flowing downward in the annular space surrounding the plain pipe of the tube well, and entering the strainer portion of the tube well along with the good water. A fairly simple method of exclusion is as follows :—

Assuming that the boring is completed and the tube well ready to be lowered into position ; the top of the convoluted tube well to be below the bottom of the impervious stratum. An expanding plug is arranged on the plain pipe of the tube well, in such a position that when the tube well is lowered and resting on the bottom of the bore hole, the plug will be opposite the impervious stratum. A suitable plug can be made from an old inner tube of a large size pneumatic tyre, the tube is cut and cemented, a size which is to fit on the plain pipe of the tube well and is held temporarily in position by numerous bands of rubber, binding tape or sticking plaster, a small ring filed to an internal knife

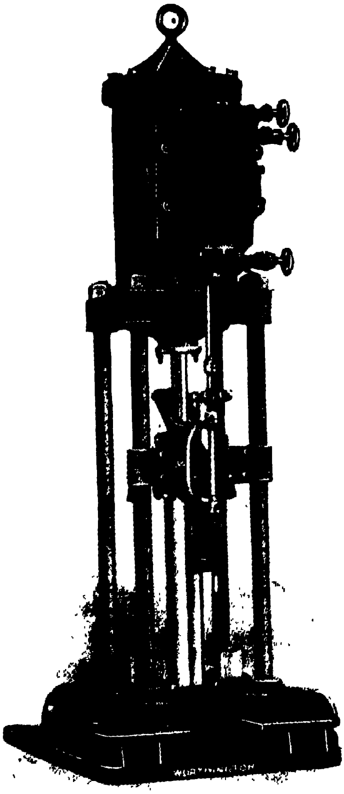


Fig. 38.—Swing type of steam drive for bore hole pumps, made by Messrs. Worthington and Co.

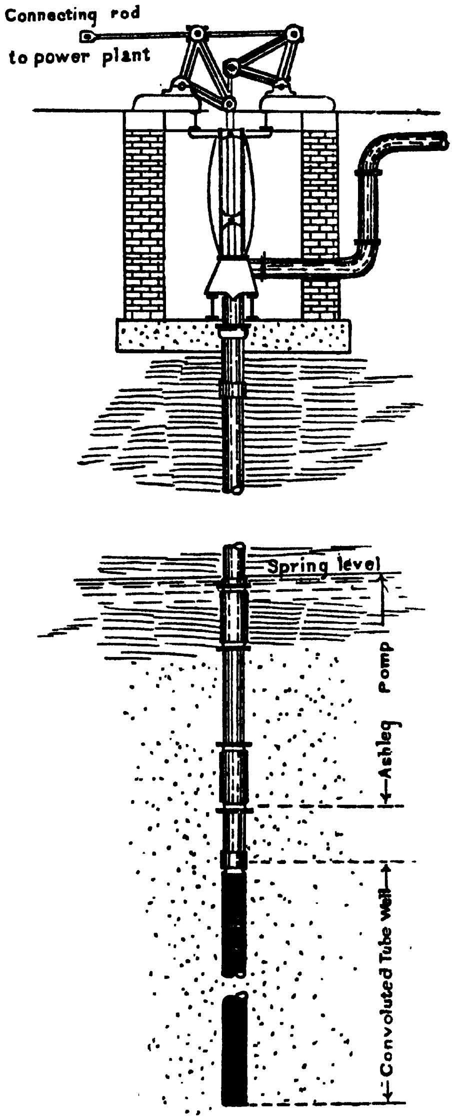


Fig. 39.—Double-acting Ashley pump with bell crank links to rods.

edge is secured to the plain pipe close to the plug and the rubber tube from the valve of the plug to the pump is looped through this ring. The tube well is lowered into position, care being taken to pay out sufficient of the rubber air tube as the tube well is lowered. The bore tube is then withdrawn until its lower edge is just above the plug; the plug is next inflated, pressing hard on the plain pipe of the tube well and on the impervious stratum, a portland cement plug is then poured in on the top of the rubber plug, a few sharp jerks on the rubber air tube will suffice to free it by cutting through on the knife-edged ring, and the bore tube is withdrawn, leaving a solid cement plug bridging the space between the plain pipe and the impervious stratum.

CONE OF DEPLETION.

WHEN several tube wells have to be sunk for a water supply, it is desirable to keep them as close as possible without the one tube interfering with the supply from another. Observations of the cone of depletion have been made in moderately fine sand for 3½-inch tube wells discharging 5,000 gallons per hour, and the points at which the cone of depletion curve cuts a horizontal plane *six inches below* the normal spring level are given in the following table :—

Head of depression in feet.	Distance from tube at which cone cuts six inches below water table.	Minimum distance apart of tubes.
2	31	62
4	47	94
6	62	124
7	70	140
8	79	158
10	96	192
12	118	236

Within safe working limits the yield of a tube well is similar to an ordinary percolation well in so far that the

discharge increases directly as the head of depression and, therefore, when once the water level in any well has been lowered it theoretically will take infinite time to recuperate the last few inches, for this reason it is considered sufficient to place ordinary percolation or tube wells at such a distance apart that their cones of depletion intersect at a point six inches below spring level.

The above figures refer to small tubes and the observations have been made before the water surface reached its natural hydraulic gradient, therefore the figures are very similar to those obtained from ordinary percolation wells.

As previously stated, the discharge obtainable from an ordinary well, varies directly as the head and this law also holds good for tube wells, being correct in both cases so long as the critical velocity of the sand is not exceeded. In capillary tubes and even in tubes of small diameter worked at very low velocities, the discharge varies directly as the head, but when the head is increased indefinitely there comes a point at which the septa between the pores of the soil is ruptured, enlarging the pores and from this point on for all increased heads, the law for flow through pipes holds good, that is, the discharge varies as the square root of the head.

In order to reduce the possibility of rupture of the septa the tube must be enlarged for increased discharges, and this enlargement is necessary in the length of the tube employed, as far as velocities through sand are concerned, but in order to reduce friction in the tube itself, the diameter of the tube has to be enlarged and the increased discharge has to be obtained by a compromise of these two conflicting issues.

This point will be more apparent by a reference to the following diagram.

Let A represent in cross section a tube of, say, four inches and B a tube of eight inches diameter, for convenience the tubes are shown concentric. In a unit length of A, and two units length of B, under a head of H feet, the smaller tube A discharges gallon per hour, and tube B discharges four gallons per hour, because the straining area of B is four times the straining area of A, and the infiltration velocity is equal for both tubes.*

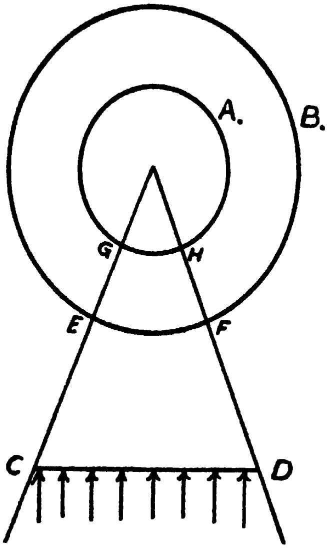


Fig. 40.

This arrangement makes the tube friction head equal in both cases. Now, referring to the cross section, in any segment CD of unit length for both tubes, the quantity of water which has to pass any given section such as CD on that segment, is gt for tube A, and 2gt for tube B, because tube B in unit length is obtaining twice the

* NOTE—This is correct when sand friction is neglected, and is introduced to show that the additional head ultimately required in tube B, is entirely due to sand friction.

water that tube A is obtaining in unit length. The infiltration velocity is the same in both tubes, because section strainer EF is twice section strainer GH. The section CD multiplied by unit length, gives the area CD, which is common to both tubes, and as gt water is passing this area for tube A, and 2gt water is passing for tube B, therefore the mean velocity for tube B is double the mean velocity for tube A.

This doubling of velocity represents a corresponding increase of sand friction, which, if the discharge of the large tube is to be maintained, must be overcome by an increase in head.

A method of calculating the ultimate vertex head of tube wells, is contained in the following paper, published recently by the author, in *Indian and Eastern Engineer.* The author has used this system on a large number of tube wells during the past six years, and the results in actual practice have proved that the method of estimating the vertex head is accurate for all practical purposes.

SUBSOIL WATER IN RELATION TO TUBE WELLS

(from an article published in *Indian and Eastern Engineer,* Dec. 1919).

BY

T. A. MILLER BROWNLIE.

DEVELOPMENT OF IRRIGATION.

DURING the past ten years considerable development in lift irrigation by means of tube wells, has taken place in India and judging by the success of most of these installations there is every prospect of a great future for this type of irrigation.

Observation of a large number of existing tube well installations has led me to conclude that, the engineers responsible for carrying out these works have

never examined the conditions governing underground water supply, and, therefore more or less frequent alterations in each installation have had to be made in order to maintain the discharge obtained in the early days of the plants installation. Where no alterations have been made it is admitted that the discharge is less than when the plant was first installed and is a gradually diminishing quantity. To rectify this defect means the increasing of the head under which the tube is worked and this (in the worst cases) frequently entails the installing of a different type of pump and higher driving power. In fact, tube wells have been installed in a more or less haphazard manner without any clear idea as to what the ultimate condition of and discharge of water will be, and I have heard the statement made that so little is known of tube wells and their behaviour in different soils that it is impossible to foretell the results likely to be obtained from them.

PERMANENT SUPPLIES POSSIBLE.

WITH this statement I am not in agreement and the object of this paper is to show that under normal conditions a permanent fixed supply from tube wells can be obtained and that the ultimate head or depression necessary to obtain this supply can be calculated with fair accuracy, and thus a chart of probable annual pumping expenditure can be prepared for a period of 12 or 15 years and the ultimate permanent recurring costs accurately estimated.

ERRONEOUS DATA.

THE present method of estimating the various unknown quantities connected with tube well water supplies appears to be based on entirely erroneous assumptions. For example, a tube well is sunk in a certain type of subsoil and a pump applied, a discharge of say, one cusec is obtained under a depression head of

X feet ; the information thus obtained is used as a base for calculating the depression head for—it may be a similar tube in exactly similar subsoil, or, it may be used as a guide for estimating larger or smaller discharges in similar or dissimilar subsoils. That something is very far wrong in this method is evident from the fact that sooner or later it is discovered that the depression head is an increasing quantity, while the discharge is a decreasing quantity. The fact being that the original trial head X was an incorrect representation of the true state of affairs, and its use as experimental data has led to very considerable waste of money in designing plant unsuited to the conditions under which it will be ultimately worked. Particularly is this the case with centrifugal pumps, which on account of the steady discharge they yield are eminently suited to tube well work ; these pumps yield their highest efficiency for a fixed discharge on a definite head, and if the head is wrongly estimated then a serious loss of efficiency is introduced.

In order to obtain a permanent water supply from a tube well it is necessary that water reach the tube through the subsoil in quantity and velocity at least equivalent to the pumping rate. If arrangements for this are not made when a tube well is first installed, then the effect of pumping for several months (or it may be a few years) is equivalent to slowly squeezing a steady discharge from a sponge, *i.e.*, the squeezing pressure has to be gradually increased and the sponge is ultimately squeezed dry. Few mechanics would think of installing a pump in a tank for a permanent water supply when the quantity of water reaching the tank per annum was half or quarter the quantity they wished to pump ; yet this is frequently done in the case of tube well installations, the resulting gradual decrease in supply and increasing head being attributed to changes in local conditions, etc. The explanation is of course in the main correct, but it should

be noted, that these changes are caused by the tube well, and are not due to climatic or geological conditions as one is led to suppose. An examination of the subsoil and accurate knowledge of the hydraulic gradient of the underground water, combined with the general geological and surface survey is absolutely essential before an accurate estimate of the conditions governing a permanent supply of water can be made.

SUBSOIL WATER.

It is well known that in order to cause water motion in a lake, the outlet must be lower than the inlet, that is, a head is required. In the case of a lake or pond the head necessary to cause motion is very small, but if the lake is filled with gravel then a greater head is required in order to produce the same motion or amount of flow; the reason being that there is a certain amount of friction or rubbing of the water against the stones and added head is required to overcome this. If we imagine the lake filled with sand, then the head is very considerably increased in order to produce the same flow and measurements taken vertically from a fixed datum to the water surface show a very decided slope. As in the case of gravel the head is necessitated by the resistance offered to the passage of water in the fine interstices between the particles of sand, the finer the sand and the closer it is packed; the greater the resistance and the greater the head required to cause a flow through it.

HYDRAULIC GRADIENT.

Observations made during the past few years of the subsoils of the Punjab have shown that the slopes necessary to cause water motion have varied from one in 260 in moderately coarse sand to one in 175 in fairly fine sand.

In gradients flatter than this, in each type of sand, there is no apparent motion. *Capillary attraction*

interferes with the true flow and investigation into the forward motion becomes greatly involved. Observations indicate that any lateral or forward motion of water, where the hydraulic gradients are slightly less than those mentioned, is so slow that for practical purposes it may be neglected, the actual velocity probably not exceeding a few inches per day. When water is flowing through sand the hydraulic gradient is a straight line as long as the sand is all of similar grade and density, and all cross sections on the line of flow are of equal area.

This may not be perfectly clear, but, if likened to a pipe of uniform bore discharging from an open end, the fact becomes obvious.

In a long pipe of gradually diminishing diameter discharging water, the hydraulic gradient for this becomes a curve. The large diameter of pipe at the upper or reservoir end has a hydraulic gradient of slight slope, the next section of pipe of slightly smaller bore requires a greater head to overcome its friction and the hydraulic gradient is steeper—and so on to the final section of small bore pipe which requires a considerable head and thus a very steep hydraulic gradient to overcome its friction. Exactly the same takes place in sand when the water flow is concentrated on a point, as in a well. The waterway area through the interstices of the sand is gradually diminishing and hence an increasing head is required to maintain the discharge as the water approaches the well. Thus we have the curved line generally referred to as the cone of depletion for wells, tube wells, etc.

When pumping is first started on a tube well the hydraulic gradient is steep, but is artificial only, and as the water is gradually withdrawn from the cone thus formed, the gradient gradually flattens out and on reaching its limiting hydraulic gradient the supply ceases; this may take several months according to the amount of

depression provided for, it being only a question of the rate of pumping compared with the capacity of the cone reservoir. What has apparently never been done is to estimate the source of water supply and provide an area sufficiently large to accumulate the quantity of water required for the discharge. In many districts direct percolation from canals and rivers provides a large portion of the underground water supply, this can be gauged and therefore I will only consider those districts where the hydraulic gradient is flatter than the limiting hydraulic gradient, and in which rainfall is the only practical source of supply. Assume that a tube well is required with a constant discharge of 1½ cusecs, the annual rainfall of the district being 26 inches, of which one-third is absorbed or say nine inches. One and a half cusecs of water flowing constantly for one year amounts to 47,204,000 cubic feet, and this being supplied by nine inches of rain requires an area of 63,000,000 square feet. A circle of this area would have a diameter of 8,920 feet approximately. With a limiting hydraulic gradient of one in 200 on a radius of 4,460 feet the depression head amounts to just over 22 feet, to this must be added approximately five feet, the head required for the trumpet mouth portion of the cone to overcome the increased friction as the water approaches the tube.

It will be observed that I have calculated the cone as having straight sides and have added a few feet for the trumpet mouth portion of the cone. The influence of the trumpet mouth is only observed a few hundred feet from the tube, the remainder of the curve being so nearly flat that it may be considered the straight line of an unrestricted hydraulic gradient. The error thus introduced is slight and the calculations very considerably simplified.

In conditions as mentioned above it will be observed that for a permanent discharge of 1½ cusecs a total

depression head of 27 feet should be provided, for, and the cone of influence will be over $1\frac{1}{2}$ miles in diameter.

The actual quantity of water stored in this depression cone is as follows :—

Volume of cone is roughly 462 million cubic feet and quantity of water stored in this grade of sand is 30 per cent. or 138 million cubic feet.

In the above example I have assumed the subsoil water surface to be level, this seldom occurs, but when there is no practical subsoil water motion, the hydraulic gradient is less than the limiting gradient and with a slope of any degree the cone would form an ellipse for its base. In dealing with these slight gradients the assumption that the base of the cone is a circle instead of an ellipse simplifies calculation and the error introduced is negligible.

DEPRESSION RATE.

ALTHOUGH provision has been made in this example for an ultimate depression head of 27 feet, it will be some considerable time before this head is reached. In the first year of pumping 47 million cubic feet of water will be withdrawn from the subsoil. This represents a cone of approximately 5,600 feet diameter and vertex 14 feet below natural water level. Rainfall absorbed in this cone will be 18 million cubic feet. For the second year's pumping the vertex head is gradually depressed to 16 feet, thus bringing a larger cone into operation containing an additional 17 million cubic feet of stored water and capable of absorbing 24 million cubic feet. In the third year the vertex head has to be still further depressed to 18 feet in order to obtain the additional storage capacity and collection area to maintain the years pumping. From the sixth to the tenth year the depression rate is markedly decreasing; only one foot increase taking place in this period and this suffices to

keep up the supply required for each year's pumping. The extension from 22 feet to the approximate permanent vertex head of 22·3 feet would actually take from the tenth year till nearly the eightieth year of pumping. To each of these vertex heads the trumpet mouth head of approximately five feet has to be added, thus bringing the permanent total head to approximately 27 feet. The importance of estimating the permanent depression head in tube well installations cannot be too forcibly impressed, as an error in judgment or an error based on inspection of an installation during the first few years of its working may involve the construction of a costly scheme which otherwise would not have been undertaken; or in an expenditure in practically reconstructing and refitting an installation a few years after its supposed completion. In addition to this, estimates based on incorrect vertex heads for recurring costs would soon be seriously exceeded, a subject for grave consideration when water is required for irrigation purposes.

The quality of the subsoil and its hydraulic gradient having been examined and percolation estimated from a surface and a geological survey, and from the valuable records maintained by the Irrigation Department it is a simple matter to arrive at a very close approximation of the ultimate permanent head required for a given discharge.

When a lift irrigation installation consists of a battery of tubes the necessity for correctly estimating the total depression head is of even greater importance than with single tubes, for, if the head is underestimated, not only are the initial cost and recurring costs of the scheme seriously increased, but the head being underestimated reduces the cone of influence and tubes are thus placed much too close to one another, enormously reducing the possible discharge.

An example of this was brought to my notice some years ago when a proposal was made to sink some 20 tubes, each for a proposed discharge of two cusecs, the distance apart of the tubes to be half a mile and the full depression head for two cusecs discharge was estimated at less than 18 feet, normal water level was roughly 12 feet below ground surface. I pointed out that the estimated depression was inadequate and the scheme would not be economical as total depression would be nearly* thrice the depth from ground surface to normal water level, also that cones of depression would seriously interfere with one another at the intervals proposed and cause a further increase in head.

In the district in which this scheme was proposed I understand the limiting hydraulic gradient is one in 190 and only in one small portion of the district does the hydraulic gradient exceed this limit, so that the subsoil water may be termed motionless. Percolation from all sources amounts to practically one foot per annum and therefore the surface area required for a single tube is 63 million square feet. This represents a circle of 8,968 feet diameter and with a limiting hydraulic gradient of one in 190 the vertex of the cone would be say 23½ feet below normal water level, adding to this the friction depression of nearly six feet the total head amounts to 29 feet, or 11 feet more than the estimate. The influencing base of the cone is over 8,900 feet diameter, and, therefore, no two tubes should be closer to one another than this distance if a permanent water supply is desired. The proposal to sink tubes at half a mile interval means that normal water level between each pair of tubes would ultimately be reduced by 16½ feet. In order, therefore, to obtain a permanent supply of two cusecs from each tube of a battery positioned at such intervals, the cone base

* Vide proceedings of P. W. D. Congress, 1917.

becomes an ellipse of approximately 2,600 feet minor axis and 24,000 feet major axis, the vertex being thus some 63 feet below normal water level. A single tube well discharging two cusecs under the conditions just mentioned would cause a cone vertex depression of 16 feet in 14 months working (see table B), a vertex head of 22 feet being gradually reached by the fifth year. Twenty-three feet would not be reached till the eighth year.

From the eighth year onwards a period of practically 20 years is required for the vertex head to alter from 23 feet to approximately 23·6 feet.

So that for practical purposes a vertex head of 23 feet reached in the eighth year is a safe estimate.

Obviously any measurements made during the first five years give no indication of the ultimate vertex head and it is only after the sixth year that the depression is slight, being 18 inches in roughly 20 years.

Table C shows the conditions of depression for a tube well discharging three cusecs from subsoil having a limiting gradient of one in 180. Here again the cone vertex is rapidly descending for the first five years of working, actually dropping 10 feet in that period. From the fifth till the eighth year there is a further drop of two feet, the maximum vertex head of just over 34 feet being approximately reached after 18 years pumping—actually reached in something like 53 years. In this case it is obvious that the pump must be designed to give its maximum efficiency between 30 and 34 feet and that its efficiency will be poor for the first three years of working.

In calculating the ultimate vertex head and rate of depression for any tube well average percolation is assumed. This is sufficiently accurate for all practical purposes as a year of complete drought would shorten

the depression time by one year, similarly abnormal rainfall would lengthen the time in proportion as the excess was above normal.

Additional to the many advantages gained by foretelling the ultimate vertex head for a tube well, consideration must be paid to these land-owners who do not possess tube wells and whose land is adjacent to tube well irrigated land. Cases have come to my notice where land-owners have been deprived of their ordinary means of irrigation by the installation of tube wells on neighbouring lands. When the ultimate vertex head has been calculated then the extent of influence of the tube is at once known.

For example the three cusecs, tube shown in table C is together with rainfall sufficient to irrigate roughly 1,000 acres, assume that the owner of this tube owns 1,200 acres and the tube is centrally positioned thereon. The tube has an influence over a circle of 12,000 feet diameter or say 2,680 acres and therefore water is being taken from under neighbouring land extending to 1,480 acres for the benefit of only 1,200 acres, and it must not be forgotten that practically this whole area will be affected in seven or eight years from the time the tube is started working.

The matter is of such importance that legislation is wanted at an early date, land-owners must be limited as to the quantity of water to be extracted from the subsoil in accordance with the subsoil quality and land area. Areas under cultivation would be greatly extended by proper conservation of water for irrigation purposes, and it does not seem unreasonable to suppose that nature has provided subsoil water storage in sufficient quantity for the economical cultivation of the lands containing these stores.

TABLE A.

Showing time depression for 1½ cusecs continuous discharge in sand of limiting gradient 1 in 200.

PERCOLATION—9 inches.

(Quantities in millions of cubic feet).

Time Year.	Vertex head.	Cone diam.	Total water cap. of cone.	Cone contents.	Percolation.	Available water in cone.	Water pumped.	Balance.
1st	14	5600	34	34	18	52	47	5
2nd	16	6400	51	(51—34)+5=22	24	46	47	—1
3rd	18	7200	73	(73—51)—1=21	30	51	47	4
4th	19	7600	86	(86—73)+4=17	33	50	47	3
5th	20	8000	100	(100—86)+3=17	37	54	47	7
6th	21	8400	116	(116—100)+7=23	41	64	47	17
7th	21	8400	116	(116—116)+17=17	41	58	47	11
8th	21	8400	116	(116—116)+11=11	41	52	47	5
9th	21	8400	116	(116—116)+5=5	41	46	47	—1
10th	22	8800	133	(133—116)—1=16	45	61	47	14
11th	22	8800	133	(133—133)+14=14	45	59	47	12
12th	22	8800	133	(133—133)+12=12	45	57	47	10
13th	22	8800	133	(133—133)+10=10	45	55	47	8
14th	22	8800	133	(133—133)+8=8	45	53	47	6
15th	22	8800	133	(133—133)+6=6	45	51	47	4
16th	22	8800	133	(133—133)+4=4	45	49	47	2
17th	22	8800	133	(133—133)+2=2	45	47	47	0
18th	22·3	8920	139	(139—133)+6	46·9	52·9	47	5·9
19th	22·3	8920	139	(139—139)+5·9=5·9	46·9	52·8	47	5·8
20th	22·3	8920	139	(139—139)+5·8=5·8	46·9	52·7	47	5·7
21st	22·3	8920	139	5·7	46·9	52·6	47	5·6
22nd	22·3	8920	139	5·6	46·9	52·5	47	5·5

Vertex head reaches the full 22·3 feet, say 77 years from start of pumping. Highest pump efficiency to be between 21 and 23 feet vertex head.

TABLE B.

Showing the depression for 2 cusecs continuous yield in sand of limiting gradient 1 *in* 190.

PERCOLATION—12 inches.

(*Quantities in millions of cubic feet*).

Time Year.	Vertex head.	Cone diam.	Total water cap. of cone.	Cone contents.	Percolation.	Available water in cone.	Water pumped.	Balance.
1st	16	6080	46	46	29	75	63	12
2nd	18	6840	66	(66—66) - 12=32	36	68	63	5
3rd	20	7600	90	(90—66)+5=29	45	74	63	11
4th	21	7980	105	(105—90)+11=26	50	76	63	13
5th	22	8360	120	(120—105)+13=28	54	82	63	19
6th	22	8360	120	19	54	73	63	10
7th	22	8360	120	10	54	64	63	1
8th	23	8740	137	(137—120)+1=18	60	77	63	14
9th	23	8740	137	14	60	74	63	11
10th	23	8740	137	11	60	71	63	8
11th	23	8740	137	8	60	68	63	5
12th	23	8740	137	5	60	65	63	2
13th	23·3	8854	143	(143—137)+2=8	61	69	63	6
14th	23·3	8854	143	6	61	67	63	4
15th	23·3	8854	143	4	61	65	63	2
16th	23·3	8854	143	2	61	63	63	..
17th	23·5	8930	147	(147—143)=4	62·6	66·6	63	3·6
18th	23·5	8930	147	3·6	62·6	66·2	63	3·2
19th	23·5	8930	147	3·2	62·6	65·8	63	2·8
20th	23·5	8930	147	2·8	62·6	65·4	63	2·4
21st	23·5	8930	147	2·4	62·6	65·0	63	2
22nd	23·5	8930	147	2	62·6	64·6	63	1·6
23rd	23·5	8930	147	1·6	62·6	64·2	63	1·2
24th	23·5	8930	147	1·2	62·6	63·8	63	0·8
25th	23·5	8930	147	·8	62·6	64·4	63	·4
26th	23·5	8930	147	·4	62·6	63	63	..
Infinity ..	23·6	8968	147	(148—147)=1	63	64	63	1

To above vertex head must be added sandfriction head or trumpet mouth approximately five feet. Highest efficiency of pump to be from 22 to 24 feet *vertex head.*

Table C.

Showing the depression for three cusecs, continuous yield in sand of limit gradient one in 180.

Total percolatlion 0·8 foot.

(*Quantities in millions of cubic feet*).

Time Year.	Vertex head.	Cone diam.	Total water cap. of cone.	Cone contents.	Percolation.	Available water in cone.	Water pumped.	Balance.
1st	20	7200	81	81	32	113	94	19
2nd	22	7900	108	(108—81)+19=46	39	85	94	—9
3rd	25	9000	159	(159—108)— 9=42	50	92	94	—2
4th	28	10080	223	(223—159)— 2=62	63	125	94	31
5th	30	10080	274	(274—223)+31=82	73	155	94	61
6th	30	10080	274	(274—274)+61=61	73	134	94	40
7th	30	10080	274	(274—274)+40=40	73	113	94	19
8th	32	11520	333	(333—274)+19=78	83	161	94	67
9th	32	11520	333	(333—333)+67=67	83	150	94	56
10th	32	11520	333	56	83	139	94	45
11th	32	11520	333	45	83	128	94	34
12th	32	11520	333	34	83	117	94	23
13th	32	11520	333	23	83	106	94	12
14th	32	11520	333	12	83	95	94	1
15th	33	11800	365	(365—333)+1=23	88	111	94	17
16th	33	11800	365	17	88	105	94	11
17th	33	11800	365	11	88	99	94	5
18th	33	11800	365	5	88	93	94	—1
19th	34	12240	399	(399—365)—1=33	93	Thirty-three additional years.		

Highest pump efficiency to be from 30 to 34 feet vertex head.

GURDASPUR TUBE WELL.

Pumping rate is 1·5 cusecs for 2,000 hours per annum.

Rainfall average for 20 years is 34 inches per annum.

Sand gives limit gradient of one in 200 approximately.

(Quantities in millions of cubic feet).

Time Year.	Vertex head.	Cone diam.	Total water cap. of cone.	Cone contents.	Percolation.	Available water in cone.	Water pumped.	Balance.
1st	7	2800	4·7	4·7	5·5	10·2	11	—0·8
2nd	8	3200	7·0	(7-4·7)—0·8=1·5	7·3	8·8	11	—2·2
3rd	9	3600	10	(10—7)-2·2=0·8	9	9·8	11	—1·2
4th	9·5	3800	12	(12—10)-1·2=0·8	10	10·8	11	—0·2
5th	9·7	3880	12·7	(12·7—12)-·2=0·5	10·8	11·3	11	0·3
6th	10	4000	14	(14-12·7)—0·3=1·0	11	12	11	1·0

Maximum vertex head reached between fifth and sixth years. Trumpet mouth approximately four feet six inches.

FEROZEPORE DAIRY FARM.

LIMIT—1-170.

DISCHARGE SAY—2 cusecs.

3000 hours per annum.

(Quantities in millions of cubic feet).

Time Year.	Vertex head.	Cone diam.	Total water cap of cone.	Cone contents.	Percolation.	Available water in cone.	Water pumped.	Balance.
1st	12	4080	15	15	8	23	21	2
2nd	14	4760	25	(25—15)+2=12	11	23	21	2
3rd	15	5100	29	(29—25)+2=6	13	19	21	—2
4th	16	5440	37	(37—29)—2=6	15	21	21	0
5th	17	5780	44	(44—37)=7	17	24	21	3
6th	18	6120	53	(53—44)+3=12	19	31	21	10
7th	18·5	6290	57	(57—53)+10=14	20·4	34·4	21	13·4

TESTING WELLS AND TUBE WELLS.

THE simplest and also the most accurate method of gauging the yield of any well is the recuperative test. The method of procedure is as follows. Assume that a percolation well is to be tested, the normal spring level being 20 feet below ground surface and the well is sunk in a soil, the critical velocity of which permits of a head of only seven feet. The depth from a fixed mark at the top of the well to water level is carefully measured and reads say 20 feet, the pump is started and water pumped down to 7 feet 6 inches below the depth recorded, the pump stopped and the exact time of stoppage of the pump noted when the depth from the fixed mark is 27 feet 6 inches, the time is again recorded when the water rises 1 foot or to 26 feet 6 inches and again when water has risen a second foot to 25 feet 6 inches and so on for every foot, up to 20 feet 6 inches. The difference between any two consecutive time readings gives the actual time the water took to rise that one foot and any slight inaccuracy in one reading is balanced in the next reading. If the time reading at 24 feet 6 inches is 10 hours 14 minutes 30 seconds and the reading at 23 feet 6 inches is 10 hours 29 minutes 30 seconds, the difference is 15 minutes for a head of four feet, the yield being 78·5 cubic feet* in 15 minutes or 1,962½ gallons per hour, and similarly for each foot of head. It will be observed that by this method the last reading will be the time taken to rise from 21 feet 6 inches to 20 feet 6 inches; this gives the yield of the well under a head of one foot. This method of counting the head as the mean depth of each foot of rise is considered more accurate than when the head is considered the lower or higher reading; as obviously when the water level is at say 24 feet 6 inches, the well

* This assumes a well of 10 feet diameter.

is yielding a greater quantity than it is by the time the water reaches 23 feet 6 inches. Theoretically, a more accurate observation would be made by considering the head to be four inches above the lower reading so that to measure discharges at even feet, the well should be pumped to a head of 7 feet 4 inches and the time taken as water rises to 6 feet 4 inches, 5 feet 4 inches, and so on ; in this way the last time reading to be taken would be when the water level is four inches below normal spring level, but as it is the last few inches which take an infinite time to recuperate it is customary to neglect six inches and consider one foot as the head for a recuperation from $1\frac{1}{2}$ feet to $\frac{1}{2}$ foot.

Tube wells which have been sunk in existing wells or in pump sumps are tested precisely as above, in the former case the existing well should be tested prior to sinking the tube well if the well is to remain unsealed and if the yield of the tube only is wanted, in which case the yield of the existing well is deducted from the combined yield of well and tube well. With large tube wells sunk in pump sumps, recuperation is extremely rapid and considerable care is required in timing and in reading the depths. A light measuring rod or tape secured to a large float is a convenient method, the tape being kept taut by passing it over a pulley and hanging a weight sufficient to balance the float, a pointer fixed to the well head will serve as the fixed mark ; as the tape rises with the water the depths can be called out and the time noted in seconds and fractions, on a stop watch.

When tube wells are sunk for direct pumping, accurate recuperation tests are impossible, as the water simply flashes up the plain tube, the simplest method in such cases is to pump as steadily as possible for a time, passing all water from the pump over a rectangular or V-shaped notch, the head being measured by a float and cord, in a small tube alongside the tube well ; or the head

may be recorded by fixing a vacuum gauge on the suction pipe. This latter method is seldom accurate as so many allowances for temperature, level, and atmospheric pressure, etc., have to be made. If two good observations are made in this way with the pump working at half speed for the second, the yield is obtained for two heads and as the discharge varies directly as the head the remaining points can be calculated.

Some engineers rely on the discharge of the pump in preference to measuring by passing the water over a notch, but this generally leads to results far from accurate : the pump speed may vary considerably, valves may be out of order, joints may not be tight, or many causes may go to produce a discharge very different to that which the pump is supposed to be yielding.

THE END.

Convoluted Tube well in operation.